TECHNOLOGICAL GAPS IN V/STOL DEVELOPMENT

By Richard E. Kuhn

NASA Langley Research Center
Langley Station, Hampton, Va.

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ABSTRACT

This paper touches on some of the primary, and some not so primary, areas in V/STOL technology requiring further attention. There are many areas where additional work will lead to performance improvements and enhance the reliability. In some cases, such as the stopped rotor and tilt rotor, additional work including flight demonstrations, will be required before a full assessment of the problems of the type can be made.

It is indicated that the primary need is that of identifying the mission to which V/STOL aircraft should be designed. In this regard, work on the noise and traffic control and instrument flight problems appear most important inasmuch as the extent to which these problems can be minimized will greatly affect any assessment of the missions for which V/STOL aircraft should be designed.

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INTRODUCTION

This paper, as requested, will review the technological problem areas hindering V/STOL aircraft development. Flight-test programs on such aircraft as the XC-142 tilt-wing V/STOL transport, the Hawker P-1127 jet V/STOL fighter, as well as innumerable design studies (refs. 1 to 5) have shown that practical V/STOL aircraft with useful payload and range capability can be built. Why then have production V/STOL aircraft not followed? The answer appears to be that, when compared with conventional aircraft, V/STOL capability always costs something. This cost, in terms of range or payload, is relatively easy to identify in design studies. The utility of V/STOL performance is easy to visualize but it cannot be quantified to the same precision as the cost can be identified. In short, as illustrated in figure 1, the cost (ref. 5) part of the cost effectiveness equation can be identified, but the effectiveness part can not. Further technical developments will reduce the cost of V/STOL performance; however, most of these developments will also reduce the cost of conventional aircraft operation. The gap between the two can be narrowed, but will probably never be eliminated.

Perhaps too much effort has been devoted to attempting to develop a new type of V/STOL aircraft that will circumvent or minimize the operational or cost penalties of other types. Each of these is optimized for the particular mission the inventor has in mind, but there is no agreement on the mission. A broad base of V/STOL technology that can be applied to a wide range of missions is already in hand. Somehow what is needed now is a clear definition of the mission (such as the supersonic transport mission of New York to Paris at competitive fare levels) to which the existing technology can be applied.

The above should not be taken to imply that there are no problems in V/STOL technology. While we can build useful operational V/STOL aircraft of many types, there are still many areas where improvements can be made and where the reliance on experimental "cut and try" procedures needs to be reduced. Having disposed of the previous bit of philosophy, the remainder of this paper will direct itself to the technological problem areas. It will begin with a brief look at the cruise performance of V/STOL aircraft followed by a discussion, first by V/STOL type and then by discipline, of the technical problems requiring further study, and conclude with a brief look at some possible future applications which it is hoped will stimulate the imagination of the reader.

CRUISE PERFORMANCE

Most of the V/STOL effort is directed at endowing conventional aircraft with vertical or short-take-off-and-landing performance. Care must be exercised in so doing to avoid unduly compromising the normal cruise efficiency of the aircraft. Figure 2, taken from reference 6, shows a comparison of the cruise efficiency, as expressed by the maximum lift-drag ratio of the aircraft, for conventional aircraft and for V/STOL design studies. The maximum lift-drag ratio of V/STOL aircraft is seen to be of the order of half that of conventional aircraft. Part of the difference is due to the smaller wing, and therefore shorter wing span, allowable on V/STOL aircraft, which results in the configurations falling at lower values of the ratio of span to square root of the wetted surface area. Part of the poor efficiency, however, arises from a higher effective skin-friction drag coefficient which indicates the need for more attention to the basic aerodynamic cleanliness of the design. V/STOL fighters on the other hand (fig. 3) indicate essentially the same level of aerodynamic cleanliness as conventional aircraft. However, the cruise efficiency is somewhat lower for the V/STOL aircraft because of the extra wetted surface area required to enclose the extra volume necessary to house the lift engines or larger-than-usual vectored-thrust cruise engines in V/STOL aircraft. This added volume also increases the wave drag at supersonic speeds, as discussed in reference 6. The added volume, therefore, must be minimized.

PROBLEMS RELATED TO SPECIFIC CONCEPTS

Stopped-stowed rotor.- In an attempt to retain the low disk loading of the helicopter and still achieve high cruising speeds, a number of stopped-stowed rotor concepts are being studied. One of these is the Hughes' rotor-wing concept shown in figure 4. In this design, a three-bladed rotor with a large rigid center section is used in hovering and low-speed flight. In transition from helicopter to airplane flight, the rotor-wing first converts to auto-rotational flight and after a further increase in speed obtained from the airplane propulsion system, the rotor-wing is stopped in the position shown to become the wing for airplane flight. Full details of the conversion procedure in both directions are given in reference 7.

The principal problem associated with the conversion from wing-borne to rotor-borne flight is the possibility of a large attitude disturbance during the first revolution of the rotor. The aircraft disturbance is due to an oscillation of the lift center of pressure in a longitudinal (top of fig. 5) and lateral direction at a frequency that is simply the number of blades multiplied by the rotor rotational speed. The results of a wind-tunnel study indicate that large-amplitude cyclic pitch is one means of eliminating the source of the aircraft disturbance for a three-bladed rotor-wing aircraft. In addition, the selection of four blades (bottom of fig. 5) on a rotor-wing aircraft may so substantially reduce the disturbing moments that cyclic pitch is not required to eliminate the moments. However, the resultant wing configuration is considerably less attractive for a high-speed aircraft than the three-bladed rotor. Work on the rotor-wing is being pursued by Hughes Tool Company and by the NASA Langley Research Center.

One version of the stowed-rotor approach is illustrated in figure 6. In the stowed-rotor concept, the aircraft takes off vertically as a helicopter and during transition gradually shifts the load from the rotor to the wing. At a speed greater than the stall speed of the wing, the rotor is completely unloaded, stopped, folded, and then retracted and covered with fairings to convert to the airplane configuration. The problem area here is one of reducing the weight, volume, and mechanical complexity of the stopping, folding, retracting, and stowing mechanisms. It does not appear to call for systematic laboratory research, but rather for ingenuity and inventiveness. The motto that Bill Stout had in the engineering offices when he was developing the Ford Trimotor appears appropriate; "simplicate and add more lightness." Lockheed and Sikorsky (refs. 9 and 10), both actively pursuing the stowed-rotor concept, have been conducting small-scale wind-tunnel investigations. Lockheed has continued this work at large scale in the NASA Ames 40- by 80-foot wind tunnel where they have completed the starting, stopping, and folding parts of the operation with their rigid rotor at speeds up to 140 knots. Further work is required in reducing the weight penalty of the system, and in-flight demonstrations of a research vehicle are necessary to determine the sensitivity of the entire conversion operation to maneuvering and gust inputs.

Tilt-rotor concept.- Problems associated with flexibly mounted large-diameter rotors, used for lift in hovering and propulsion in the cruise mode, appear to be the primary hurdle to be overcome in this concept. The problem receiving the most attention is that of the stability of the prop-rotor itself in the cruise mode. This problem, illustrated in figure 7, is analogous to propeller whirl flutter (ref. 11) but involves several extra degrees of freedom. In addition to the nacelle pitch and yaw flexibility of classical whirl, the stability problem for the tilt-rotor involves consideration of rotor and wing modes as well as the rigid-body modes of the aircraft as a whole. Both Bell Helicopter (ref. 11) and Vertol Division of the Boeing Company (ref. 13) are studying this problem in depth. Bell has used the dynamic model shown in figure 8 in wind-tunnel tests and is planning a similar complete model for tests in the Langley Transonic Dynamics Tunnel.

In addition to the problem of the stability of the prop-rotors themselves, there is the effect of the rotors on the dynamic stability of the complete aircraft. During evaluation flights of the Bell XV-3 tilt-rotor airplane at high speeds (ref. 14), the pilots have reported the condition in which the airplane oscillated about all axes simultaneously. An analysis indicated that this condition was due to the flapping of the rotor blades which, during an oscillation, caused the rotor motion to lag behind the angular rotation of the airplane. This greatly reduces the natural damping of the configuration and results in the oscillations observed.

Several solutions to the above-discussed rotor and airplane stability problems have been proposed and partially demonstrated. However, the problems cannot be considered solved until flight demonstrations at the full design cruising speeds have been made to fully assess and demonstrate the effectiveness of the proposed solutions. The U.S. Army is currently evaluating proposals of tilt-rotor and stowed-rotor designs submitted in a competition to choose a design for construction and flight test in their Composite Research Airplane Program.

Tilt wing.- Because of the extensive wind-tunnel and flight-test development work on this type, it is the most advanced (other than the helicopter) of the various V/STOL types. It has become, in many design studies, the standard of comparison, the "one to beat" so to speak. The extensive work to date has defined the principal features of the configuration and the operational capability of the type. There are areas, however, where improvements would be desirable. Reference 15, for example, discusses the wing-propeller geometry that is required to delay the wing-stall problem in transition to the point where adequate descent capability can be achieved. Additional work in this area directed toward reducing the size of the wing would improve the cruise performance of the aircraft. Reference 16 touches on the same point and also points out the ground-induced disturbances that occur at speeds between 10 and 30 knots and require placarding of the aircraft against flight within ground effect in this speed range. These ground disturbances arise from the effects of the slipstream impinging on the ground, flowing forward ahead of the aircraft, and creating a disturbed region through which the airplane must fly. Work to reduce these effects would improve the overload STOL performance of this type which is now limited to take-off distances of at least 500 feet over a 50-foot obstacle.

The problem of predicting the static thrust of the propellers for a tilt-wing aircraft is probably the most critical problem from the point of view of design and performance prediction. This point is illustrated in figure 9 where the static thrust measured on the propellers proposed for the XC-142 airplane was found to fall far below that originally predicted. A satisfactory propeller was arrived at by using a blade with a much wider tip than that originally proposed. The reason for the importance of the tips is shown in figure 10 which is a photograph of smoke flow in the tip region. In this photograph, the axis of rotation of the propeller is along the lower edge of the figure and the flow through the propeller is from left to right. Smoke is being introduced outboard and downstream of the tip of the propeller. As the photograph shows, the flow at the tip is forward into the tip and then spanwise along the outer portion of the blade, showing that most of the contraction of the slipstream is taking place at the plane of rotation. The photograph clearly shows tip vortices at several stations downstream of the blade.

Texas A & M Research Foundation, under NASA grant, is doing both experimental and theoretical work on the static thrust of propellers. In addition, the propeller companies are, of course, attempting to upgrade their abilities to predict static thrust as well as working on the related problems of reducing propeller weight and improving reliability (ref. 17).

Fan-in-wing configurations.- The development of high-pressure-ratio fans is the primary item hindering the development of fan-in-wing designs. Recent design studies of fan-in-wing type configurations have shown that fan pressure ratios of the order of 1.3 to 1.4 are required to make these aircraft competitive with other V/STOL types. The reason for this is shown in figure 11. With the low-pressure-ratio first-generation fans flown in the Ryan XV-5A aircraft, a relatively large wing area was required to adequately enclose the fan in the wing. Even with the low aspect ratio employed in the XV-5A, this resulted in a wing loading which is uneconomical by today's standards. In order to reduce the wing area for acceptable cruise performance, it is necessary to reduce the diameter of the fans, and if the thrust is to remain constant, the pressure rise of the fan must go up.

The primary problem of the fan-in-wing configuration, at this time, is developing these higher-pressure-ratio fans to operate satisfactorily in cross flow, as depicted in figure 12. In transition, the flow through the front and rear of the disk varies both in direction and velocity. Also the blades on the advancing and retreating sides of the disk experience quite different angles of attack and velocities relative to the blade. The problems of achieving satisfactory aerodynamic and mechanical performance under these conditions are aggravated by the higher pressure rise and higher transition speeds associated with the high wing loading configurations. The work on the fan-in-wing concept has been spearheaded by General Electric and the NASA Ames Research Center (ref. 18). Two 1.3 pressure ratio lift fans are being built by General Electric for tests in the Ames 40- by 80-foot tunnel next year to investigate these problem areas. In addition, the NASA Lewis Research Center is initiating a program to look at the fundamentals of fan-in-wing aerodynamics in the cross-flow situation.

Another problem of the classical fan-in-wing configuration is the relatively poor STOL performance in the overload condition as shown in figure 13 (ref. 5). The thrust-weight ratio required for good STOL performance is a function of the load distribution. Configurations such as the tilt-wing and deflected-slipstream STOL types have a relatively uniform distribution of load over the span and can, therefore, achieve fairly short field performance with relatively low installed thrust. Current fan-in-wing and jet types, however, carry most of the load on the jets or fans. The wing is only able to operate at something equal to, or less than, its power-off lift coefficient. As a result, VTOL-type thrust-weight ratios are required at field lengths of the order of 1,000 to 2,000 feet. Several alternate approaches are being tried in an effort to improve the STOL performance of fan configurations. As shown in figure 14, reconfiguring from two to six fans in the wing in a spanwise row produced modest gains. Somewhat surprisingly, the deflection of the slipstreams from four cruise fans by a double-slotted flap system was much more effective and almost as good as a full-span jet flap. The deflected-slipstream cruise fan work is being done by the NASA Langley Research Center (ref. 19), and additional configuration work on the classical fan-in-wing is being pursued by the NASA Ames Research Center.

Still another approach is the vectored-thrust propulsive-wing type of configuration shown in figure 15. This configuration is being investigated by Vought Aeronautics (which refers to it as their ADAM II configuration) (ref. 20) and by the NASA Langley Research Center. Four fans are installed in the wing but with the plane of fans vertical so that the air is taken in through the leading edge and exhausted through the bottom of the wing at the appropriate point for minimum pitching moments or rearward at the trailing edge in cruise. In addition, a nose fan is employed for pitch control in those configurations aimed at achieving VTOL performance. At this point in the development, the propulsive-wing concept shows little gain in STOL performance over that of the classical fan-in-wing because of the very short-span, low-aspect-ratio configuration employed. The concept needs to be developed into configurations employing many more fans per semispan.

<u>Jet-lift configurations</u>.- The configuration of jet V/STOL aircraft is dictated almost entirely by the cruise configuration performance requirements. The design problem is to install the extra thrust in the form of vectored

thrust engines or lift engines with a minimum penalty in cruise drag, installation losses, and interference effects.

Interference effects in transition is a problem area that seriously affects the design of the control system and the STOL performance. As shown in figure 16 (ref. 21), the streams from the lifting engines of a jet V/STOL aircraft in transition are swept backwards by the oncoming stream and transformed into a pair of rolled-up vortices. The interaction between the free stream and the jet streams, including the rolling-up process, induces suction pressures on the lower surface of the wing and tail and also causes a general downwash in the region of the airplane. As a result, interference effects such as those shown in figure 17 are experienced. The suction pressures cause a loss in lift as the velocity is increased, and because the suction pressures are generally located in the regions behind the lifting jets, a nose-up pitching moment is induced even for the tail-off case. In addition, the induced downwash produces a down load on the tail causing an additional nose-up moment if the tail plane setting is not changed to compensate. The origin of these interference effects is fairly well understood (ref. 22). There have been sufficient experimental data accumulated, principally by the RAE in England, ONERA in France, and the NASA at Langley Research Center (refs. 21 to 25), so that the design principles that should be employed to minimize these effects are understood in a general sense. However, a reliable method of predicting these effects in the early design stage, prior to wind-tunnel tests, is needed.

Another problem area is the aerodynamic suck-down experienced by a jet V/STOL airplane in ground effect. As shown by the sketch at the right of figure 18, this down load is induced by the action of the jet entraining ambient air as it spreads out radially from the point of impingement on the ground. The entrainment action lowers the pressure under the wing and fuselage of the aircraft causing the down load. These phenomena are well understood and the down loads induced can be calculated for the single-jet case by the empirical method developed by L. A. Wyatt (ref. 26). As shown by the data presentation, full-scale and model data on the X-14 airplane (which has two jets placed close enough together to be considered a single jet) are in good agreement with the calculation. Unfortunately, the same cannot be said for the multiple-jet case. As shown by the sketch on the right of figure 19 (ref. 24), when two or more jets are placed in proximity to each other, their outward flow of air along the ground surfaces meets between the jets causing an upflow, inducing lifting pressures on any surfaces in that region. The data (ref. 27) show that as one proceeds from a single to twin and to four jets and then to various spacings of four jets, the adverse ground effects are reduced and in some cases can become favorable ground effects. There is a large body of data on multiple-jet configurations; however, little of it is of a systematic nature, and there is, at present, no method of predicting the ground effects on multiple-jet configurations. Therefore, reliance must be placed on experimental studies.

The magnitude of the aerodynamic ground effects that may be encountered on a projected design is of vital importance in the preliminary design stage inasmuch as it directly affects the gross weight that a given engine installation can lift. Means of predicting these effects are badly needed. Unfortunately, only the NASA Langley Research Center is known to be embarking on a systematic investigation to study these multiple-jet ground effects.

The problems of hot-gas ingestion on jet VTOL aircraft are even more poorly understood than the aerodynamic ground effect. As shown in figure 20, there are three factors affecting the inlet temperature rise that can be experienced. In the upper left, the sketch indicates a single-jet configuration with the jet exhaust impinging on the ground and flowing out equally in all directions. Some of the ambient air at the interface is heated by the outward flowing jet sheet and rises due to buoyancy so that it can be ingested into the inlet. If this was the only source of hot-gas ingestion, the problem would not be serious, inasmuch as the temperatures involved from this source are relatively low. The wind, however, as shown by the sketch at right, can blow the outward flowing sheet of air directly back to the aircraft causing a significant rise in inlet temperatures. The most serious problem is that referred to as the "fountain effect" depicted at the bottom of the figure. This is the same upward flow of air between the jets that produced the favorable aerodynamic ground effect. However, in considering hot-gas ingestion, this upward flow is unfavorable in that fairly large amounts of very hot air are projected upward against the aircraft and can rise rather readily to the region of the engine inlet.

The magnitude of the inlet temperatures that can be encountered under these conditions is shown in figure 21. Time histories for only two points in the forward facing inlet on a four-jet configuration are shown. Three points are apparent from these data. Rather large increases in the temperature of the air coming into the engine can be experienced, very high rates of change of temperature can be experienced, and very large temperature gradients can exist across the face of the inlet. In the minimum, these conditions would cause very large thrust losses, but the severity of the conditions shown in this figure would be expected to cause compressor stalling resulting in total failure of the engine.

Fortunately, not all configurations need be this bad. References 24 and 28 show some of the configuration variables that can be employed to minimize the hot-gas ingestion. A considerable amount of work is needed, and is continuing, on this problem area. Figure 22 shows photographs of two models being used in these programs. The NASA Ames Research Center is using essentially full-scale models equipped with J-85 engines. The model shown in the photograph was used by Northrop in company- and Navy-funded programs at Ames (ref. 29). It employs as many as five engines mounted vertically in the fuselage center section simulating lift engines and two J-85's mounted horizontally in the aft fuselage with 90° exhaust diverters simulating the deflected-jet cruise engines. Other variations, including swing-out lift-engine arrangements, are being investigated. At Langley, an approximately third-scale investigation is being undertaken using a single J-85 engine mounted horizontally in the fuselage. The exhaust is divided and conducted by suitable multiple pipe ducting to four nozzles that can be arranged in various patterns. The data of figure 21 were taken with the configuration shown in the photograph. In addition, the NASA Lewis Research Center has recently contracted with the Northrop Corporation to conduct scale model studies of hot-gas ingestion and to study means of supressing the hot-gas ingestion employing either aircraft-mounted or ground-mounted fixes. Also Langley is supporting contract work by Bell Aerosystems on small-scale studies of the fundamentals of the flow fields involved in the hot-gas-ingestion problem.

GENERAL PROBLEM AREAS

There are a number of development areas requiring attention which tend to cut across type lines. Weight is, of course, an item of primary importance in all aircraft, but it is even more important for V/STOL aircraft which are more weight sensitive. Numerous studies of new structural concepts and structural materials such as beryllium and boron fiber composite structures are being investigated. Although not directed specifically at V/STOL applications, they will benefit V/STOL directly and will not be considered further here.

Another potential problem area that is common to almost all V/STOL types is that created by the complexity added by the V/STOL features. All have complex control systems, and in addition, each has its own peculiar complexity. With the stowed-rotor types, it is the mechanisms for stopping, folding, retracting, and stowing the rotor; with the tilt rotor and tilt wing, it is the tilting mechanism and the propellers (or rotors) with their interconnecting shafting and gearing; with the fan in wing, it is the hot-gas ducting with special joints to allow for expansion and structural flexibility; and with the jet V/STOL, it is the problems of starting, checking, and controlling a large number of engines. In each case, careful systems study and analysis will be required to design out potential trouble spots and insure adequate reliability and maintainability.

Engine development.- As with structures, a number of developments taking place in the engine field will greatly benefit V/STOL engines although not specifically directed toward them. These include the emphasis on turbine blade cooling to permit higher turbine entry temperatures and the continued compressor and burner developments aimed at higher stage loadings and more efficient and compact combustors. Only a few specifically related V/STOL items, as listed in figure 23, will be discussed here.

The introduction of the turbine engine into the helicopter was the most dramatic advance in helicopter technology in the past decade. There is always room for improvement, however. The time between overhauls on turbine engines in helicopters is considerably below that for the same engines in fixed-wing aircraft. There are a number of reasons for this. Two are listed. Helicopters are expected to operate routinely from unprepared areas. As a result, they suffer greatly from ingestion of dust and debris. The development of filters has helped; however, this is considered only a crutch. The long-term solution will require developments in at least three areas: a better understanding of the flow field around the helicopter so that inlets can be located in the cleaner areas, the development of dirt separator inlets and self-cleaning filters, and the improvement of the ability of the engine to ingest dirt without suffering damage. Another factor in the short life of turbine engines in helicopters is the deterioration of the hot section due to temperature cycling.

This arises from the short-range, frequent start-and-stop use of the helicopter which calls for frequent changes in power level. Both the dirt and temperature cycling problems will be present to some extent with the other V/STOL types, and both will require attention when and if these other types are put into service.

All aircraft can benefit by reduction in the specific fuel consumption of the engines. The helicopter is, however, probably the only V/STOL that could benefit profitably from the development of a regenerator system. It is the only V/STOL type where the power requirements are low enough so that the added weight of the regenerator schemes that exist today would be more than offset by the savings in fuel. The resulting improved range capability would considerably enhance the operational usefulness of the basic helicopter.

The principal problem facing the fan-in-wing propulsion system is that of the cross-flow effects discussed previously (fig. 12). The identification of other problem areas will have to await satisfactory demonstration of high-pressure-ratio fans throughout the complete transition speed range.

In addition to the previously mentioned complexity of operating multiple lift engines, the primary problem in lift-engine development may be their intolerance to compressor face pressure and temperature distortions. The main emphasis in lift-engine development to date has been on the achievement of high thrust-weight ratios. Thrust-weight ratios of 16 to 1 have been running for some years, and 20 to 1 engines are currently being developed. The current emphasis is rightly being placed on reducing the volume of the lift engines. The wave drag of supersonic aircraft is proportional to the magnitude and distribution of the aircraft volume (ref. 6). Lift engines, of course, permit the layout of the aircraft with a good distribution of volume. They do, however, add volume to the aircraft, and anything that can be done to minimize the added volume is important.

There is concern, however, that in an effort to improve the thrust-weight ratio and the thrust-volume ratio of the lift engines, insufficient attention may be being placed on the ability of the engine to operate with distorted inlet temperature and pressure distributions. The work on the hot-gas-ingestion problem can be expected to minimize the distortion of the temperature profile, but not eliminate it. Likewise, lift engines will be operating in a cross-flow situation, and some pressure distortion will be present. There has been very little discussion of these problem areas in the literature, and there are no standards for either the engineers or airframers to work to. The factors involved in determining the engine's tolerance to these distortions are only imperfectly understood. At present, any problems that arise in the development of a lift engine in these areas are handled on an ad hoc basis. In general, the area of engine tolerance to inlet temperature and pressure distortion appears to be a fruitful one for further work.

The primary problem to be overcome with the vectored-thrust engine is that of fuel consumption in cruise. The vectored-thrust engine of the type used in the P-1127 fighter aircraft being produced in England offers several advantages. The P-1127 is the simplest V/STOL aircraft flying, having only one engine and only one extra control in the cockpit. Also having only one engine that is large enough to lift the aircraft in vertical flight gives this type excellent maneuverability and rate of climb. With the renewed interest of the military in maneuverability, it is rather surprising that this type of aircraft has not received more attention in this country. The primary problem of this type is the high specific fuel consumption in cruise as depicted in figure 24 (ref. 30). Because the engine must have sufficient thrust to lift the aircraft vertically, the thrust available in cruise, shown by the symbol, is very much greater than the thrust required for cruise. As a result, the engine must be operated in the highly throttled condition, and the fuel flow is considerably higher than that for the cruise engine of a lift-engine configuration designed for the same mission. There are a number of ways to improve this situation. The use of higher turbine entry temperatures and the use of a take-off boost such as plenum chamber burning can basically resize the engine so that the engine is not running as highly throttled in the cruise condition. Use of the variable-geometry features, including variable stators in the turbine, can flatten the curve considerably by increasing the thrust of the fan section and decreasing the hot-section thrust during the part-power operation. A number of these items are being developed for other engine applications, but there is no work in this country on vectored-thrust engines designed to be the sole lifting element of a single- or a twin-engine vectored-thrust V/STOL fighter configuration. Fortunately, our friends, the British, are continuing the development of this engine type.

Noise.- Noise is the most critical problem area in V/STOL development. It is a paradoxical situation. On one hand, there is the desire to operate from close-in bases. On the other hand, power must be increased (with respect to conventional aircraft) in order to achieve the V/STOL performance required for this close-in operation with the result that the noise is increased. Up to this point in V/STOL development, the primary emphasis has been placed on the performance capability of the aircraft. Now that reasonable performance is being obtained, it appears appropriate that more attention should be directed at achieving acceptable noise levels.

The problem of determining acceptable noise levels for close-in operation is one of the most important problem areas. Fortunately, there are a number of studies going on that will be as applicable to V/STOL aircraft as to conventional. Continuing studies of man's ability to perceive and tolerate noise are going on at North Carolina State University, and various surveys of the noise in the vicinity of airports and the reaction of the inhabitants of the area to aircraft as well as other industrial noise are being made by TRACOR of Austin, Texas. In other areas the question of how to rate noise is receiving renewed investigation. The familiar perceived noise level concept which weights the noise levels in various frequency ranges according to the sensitivity of the human ear in these frequency ranges does not take into account the effects of the duration of the noise (ref. 31) or the effects of pure tones such as are contained in compressor noise. Bolt, Beranek, and Newman are making studies of ways to incorporate these pure tones into the perceived noise level rating system.

A technique for synthesizing aircraft noise in the laboratory is being developed by the Vertol Division of Boeing and is being used in a study of the acceptability of noise expected from a family of V/STOL aircraft. This is basically a laboratory technique. The noise of the aircraft is built up on magnetic tape from the expected frequency content. The noise of helicopter, propeller, tilt-wing, fan, and jet configurations will be synthesized. These sound tracks, along with those of conventional aircraft, will be played for groups and rated comparatively by human subjects.

The effects of duration of the noise as well as data for evaluation of the validity of some of the above laboratory results will be obtained from aircraft flyovers which will be conducted at the NASA Wallops Station using real V/STOL as well as conventional aircraft. This work will be conducted by Stanford Research Institute under NASA contract using human subjects in indoor and outdoor environmental conditions to obtain comparative ratings.

The most serious problem is that of reducing the noise produced by V/STOL aircraft (refs. 32 to 35). Even the helicopter, which has the potential of being the quietest of the V/STOL aircraft types, has a noise problem. This is the rotor blade "slap" which gives it a very characteristic and easily identified signature. The source of this "slap" is believed to be the intersection of the tip vortex trailing from one blade by a following blade. The University of Southampton in England is investigating the fundamentals of helicopter noise in general and of the rotor "slap" problem in particular. In addition, the helicopter companies as well as the NASA Langley Research Center are investigating various means of altering the position or intensity of the tip vortex in an effort to alleviate this noise problem.

The noise level of V/STOL types other than the helicopter can spread over a wide range as shown by figure 27. These data were taken from the V/STOL feasibility studies reported in reference 1. In these studies, the primary emphasis was on performance, and the range of noise levels shown is a result of both differences in configuration and in differences in the approach of the companies to estimating the noise. The main point is that all of these noise levels are high, and some means of reducing them must be found if these aircraft are to be used in urban areas. Fortunately, a number of studies currently underway are directed toward the reduction of the noise of conventional aircraft and will have direct application to some of the V/STOL types.

NASA Langley Research Center is conducting a fundamental study of the source and means of reduction of compressor noise. The experimental compressor is shown installed in the anechoic chamber in figure 28. The inlet of the axial-flow, shaft-driven compressor is shown with a section of the anechoic wall removed temporarily while instrumentation is being installed. The equipment is designed to investigate the effects of number of blades, clearance between the blades and stators, tip clearance, stage loading, tip speed, blade configuration, and inlet duct treatments. Preliminary results have shown dramatic reduction in noise level when the inlet flow is choked on the inlet guide vanes (ref. 36). Also, the NASA Lewis Research Center has initiated a broad general research program directed at designing "quiet" engines. In the area of propeller noise, only small efforts are currently being made. Bell Helicopter is making an exploratory investigation of the effects of blade tip shape, and an empirical method of improving the accuracy of estimates of propeller noise is being investigated at the NASA Langley Research Center.

The most ambitious noise suppression programs currently underway are those sponsored by NASA at Boeing and Douglas to investigate means of treating the inlet and exit ducts from fan engines to reduce their noise (fig. 29). Douglas will be using acoustical treatments in both the inlet and exit ducts. Boeing will be using a longer inlet with provision for choking and a longer exit duct from the fan with acoustical treatment. Both programs will begin with analytical studies and progress through model tests and full-scale flight tests and demonstration with treatment on all four engine nacelles. In addition to studying the noise reduction itself, economic studies of the penalty due to weight and performance degradation will be made.

While much of the current work on noise reduction is not specifically related to V/STOL aircraft, all of it can have application and much of the V/STOL development work in the future should incorporate results of this work or be on configurations that can take advantage of the noise reduction principles that are being developed.

Traffic control and instrument flight.- Another pressing problem in commercial V/STOL development is that of merging the V/STOL traffic with the already dense conventional traffic in the neighborhood of the city. The primary advantage of V/STOL aircraft in commercial operation is expected to be their ability to operate from bases much more convenient to the traveling public than conventional airports. They may not be downtown, but they will be closer in than conventional airports. In many localities, landing approaches to potential sites for these bases conflict with conventional airplane traffic. New York is, of course, the worst example with the air space over New York almost completely saturated by conventional traffic and considerations of a new conventional airport being given to sites as much as 50 miles from the city. One possible means that has been suggested for handling this problem would be for the V/STOL traffic to operate under the conventional traffic as shown in figure 30 (ref. 5). This, of course, aggravates the noise problem previously discussed and only partially eases the traffic problem, inasmuch as two traffic systems now have to be handled.

A related problem area is that of flight under instrument weather conditions with the V/STOL aircraft. Under visual flight conditions, the aircraft could make a direct approach to the landing site as shown by the dotted lines in figure 30. Under instrument conditions, however, with today's instrumentation, it is necessary to set up a time- and fuel-consuming approach pattern. The details of this pattern are shown in figure 31 (ref. 37). It must be emphasized that the need for this pattern is dictated by the techniques that must be used today. The development of instrumentation and displays that do not require the pilot to set up this time- and fuel-consuming approach pattern is vital to commercial V/STOL development. With today's instruments, however, the pilot must read and interpret the information displayed on each instrument in succession. He follows the practice of scanning the instruments. Under these conditions, he can change only one variable such as speed or altitude or direction at a time. He cannot make the sweeping, turning, descending, and slowing approach which is characteristic of the helicopter approaching a landing site under visual conditions. The time builds up because of the time required to restabilize the airplane every time a change is made. Figure 31 illustrates the procedure. Before intersecting the fix, the airplane must be slowed to minimum airplane speed and converted to the approach condition (lift engines started or fan doors open and fans started, etc.). Passing the fix, the airplane is turned onto the downwind leg, and about 1-1/2 minutes are required to slow the airplane to a speed approaching that to be used in the final approach and to properly aline the airplane. The airplane can then be turned onto final approach. About a minute is required to make the turn and another minute is required to enable the pilot to aline himself with the approach localizer before reaching the outer marker to begin his descent. Again about 1-1/2 minutes are required to bracket the glide path before he is expected to achieve visual sight of the intended landing site. Experience indicates that speeds of the order of 50 to 60 knots may be required for the pilot to make acceptable approaches with today's instrumentation; therefore, something of the order of 1/2 minute must be allowed to further decelerate the airplane to hovering condition before touching down.

The entire procedure takes 5 to 6 minutes as contrasted to the 1 to 1-1/2 minutes required on the visual approach. The extra time is expensive in fuel consumed, in airspace, and because it reduces the time saving that would normally be expected to accrue due to close-in operation. A number of programs are underway in an attempt to develop better displays for the pilot. The NASA Ames and Langley Research Centers are both working on the problem and Bell Helicopter Co. has been working under military sponsorship for a number of years. Figure 32 shows equipment being used by Langley in their program (ref. 38). A special GSN5 radar located at the NASA Wallops Station provides a unique research tool serving two purposes. It provides a radar link with the aircraft to drive the pilot's displays as well as plotting a real-time record of the actual approach flown by the pilot. Both straight-in and curved approaches can be flown, and displays ranging from flight director to displacement type or so-called contact analog displays are being investigated. Conventional aircraft as well as V/STOL aircraft ranging from the Bell 204-B to the Hawker P-1127 jet VTOL fighter are being used in conjunction with this equipment.

The type of thing that could be done in studies of the traffic control problem is represented by the supersonic transport air traffic control simulation that was used by NASA and the FAA in studying the problems of handling the supersonic transport in conventional traffic. As shown in figure 33 (ref. 39), this consisted of four major elements. A simulated supersonic transport cockpit was set up at Langley and driven by analog computers to provide the proper displays to the pilot. Position information was fed on telephone lines to the FAA's NAFEC Facility at Atlantic City. Here a simulated air traffic control center is set up to study air traffic control problems. The subject aircraft is displayed on the radar scopes along with other simulated traffic from target generators associated with the air traffic control simulation. By this method both the characteristics of the supersonic transport and the characteristics of the air traffic control system could be varied and their effects on each other studied. A similar system is being used by the FAA at NAFEC in the study of a V/STOL traffic control problem presented in figure 29.

Control and stability.- The primary unresolved factor in the stability and control area is the effect of aircraft size on the control power requirements. One school holds that the control power requirements should be independent of the size - that the pilot requires the same maneuverability of the aircraft regardless of its size. The other school holds with the philosophy used in developing the military helicopter specifications and the recommendations of AGARD Report 408 (ref. 40) - that the control power required decreases with aircraft size, and that size also approximately reflects mission requirements (that is, a transport is not expected to be as maneuverable as a fighter). In AGARD Report 408 and the military specifications the control requirements are stated as a function of weight of the aircraft to represent size as shown in figure 34.

The control system of a V/STOL aircraft must meet two needs: to maneuver the aircraft and to compensate for gusts and trim changes. The angular acceleration required to compensate for gusts and for trim changes can be analyzed readily from wind-tunnel data for any particular airplane configuration. As shown in figure 34, the disturbances to an aircraft due to gusts decrease rapidly with size. The amount of control power required for maneuvering the aircraft is harder to define. It is now generally conceded that on the roll axis at least somewhat more than the AGARD recommendation should be provided. The question is how much? One design study (ref. 41) required the roll angular acceleration to be 1 radian per second squared as shown in figure 34. Of course, power must be used to produce the rolling moments required to achieve these accelerations, and the higher the acceleration required, the more serious the penalty in terms of power required and overall aircraft weight. Studies of the effects of reducing the control power from the study requirement to half that level, which still is considerably in excess of AGARD 408 for transports in the 100,000-pound gross weight category and over, were made. The results shown in figure 35 show that the gross weight could be reduced by about 10 percent by reducing the control power requirement to half, the range shown depending upon the type of control system used. It is, therefore, readily apparent that a more precise definition of the control power requirements for large V/STOL aircraft is badly needed. Both Langley and Ames Research Centers are giving attention to this problem as is an AGARD committee which is a follow-on to the committee which prepared AGARD Report 408.

Again, because of the costs in terms of power and aircraft weight required to provide the moments to counter trim changes, it is important to design the aircraft for a minimum of trim changes. The pitch-up problem that can be present with swept-wing fighters and transports can be aggravated by the previously discussed induced effects of the downward deflected jets. Care must be exercised to see that these effects are minimized. Also large rolling moments can be encountered in sideslip conditions as shown in figure 36. It is not sufficient to tell the pilot not to sideslip the airplane because it has been found that when a pilot is flying in proximity to the ground he flies by the ground and not by the relative wind. He can, therefore, find himself at large sideslip angles unintentionally. The sideslip angle that can be encountered under such conditions is illustrated at the top of figure 36 for a 30-knot cross-wind condition. The rolling moments that can be encountered, labeled "control required," under these conditions is shown at the bottom of the figure. These arise from a combination of the flow into the inlet and the interference effects due to the flow at the exit. Although shown for jet VTOL aircraft, similar rolling moments are experienced on fan-in-wing configurations as well. These data are for zero roll angle. Additional rolling moments are created by the roll attitude of the airplane. In this case, right wing down would add to the rolling moments shown. The seriousness of the problem is shown by the proximity of the control required to the control-available curve. There is, literally, little margin for complacency. Adding to the problem is the reduction in control effectiveness of the wing-tip jets with speeds as shown. This latter problem has probably been investigated to the extent necessary for design purposes (ref. 42).

Ground effects.- The lift loss on STOL aircraft due to ground proximity is another problem requiring further research. The lift to support V/STOL aircraft at very low speeds is developed by deflecting the mass flow from the propulsion system down at large angles to the direction of flight, vertically for hovering. During take-off and landing, the proximity of the ground, of course, interrupts this flow with attendant effects on the performance of the lifting system. As is shown in figure 37 (ref. 43), the slipstream from the deflected slipstream configuration can be projected ahead of the aircraft, causing the disturbed region through which the aircraft must fly. As shown by the vectors on the sketch of the wing configuration, the proximity of the ground also causes a loss in lift and a forward rotation of the lift vector which amounts to a reduction in induced drag. As shown by the data at the right, this loss in lift resulted in an increase in sinking speed for the Vertol VZ-2 tilt-wing research airplane as the ground was approached. Similar effects have been experienced by the XC-142 transport (ref. 44). The data of figure 38 (ref. 45) show that these same effects are also to be expected with jet flap configurations and that the magnitude is similar for similar operating conditions. Although good agreement exists between the three sets of data shown in figure 38, this is not to be taken as a universal curve. The loss in lift has already been demonstrated to be a function of the out-of-ground-effect lift coefficient at which the wing is operating. The effects of many other variables such as aspect ratio and percentage of the wing span affected by the propulsion system remain to be investigated.

Facilities.- The development of V/STOL aeronautics has had to rely heavily on experimental work because, in order to develop the lift at low speeds, the mass flow from the propulsion system must be directed downward at large angles to the direction of flight. Under these conditions the normal small-angle and inviscid-flow assumptions of classical aerodynamic theory can no longer apply. In addition to flight tests, the wind tunnel has been the primary development tool. It was discovered quite early in the game that, because of the large flow deflections involved, the models had to be much smaller with respect to the tunnel-test-section dimensions than was adequate for conventional testing. Also an entirely new approach to the wall corrections problem had to be developed (ref. 46). Because of the problems of installing power in the models, it was not possible to reduce the model size sufficiently for compatibility with most of the 7- by 10-foot and 8- by 12-foot tunnels normally used for airplane development. As a result, various diffuser and entrance-cone-test-section arrangements were initially set up. Recently four new wind tunnels designed for the testing of scale models of V/STOL configurations were started. The Lockheed-Georgia wind tunnel is now operating, and construction is underway for the wind tunnels for the Boeing-Vertol Company at Philadelphia, the National Research Council of Canada at Ottawa, and the NASA Langley Research Center.

These facilities will fill a need for adequate equipment for the test of scale models of V/STOL aircraft. However, the need exists for equipment for development work on full-scale, or at least large-scale, models and aircraft components. The only two really large wind tunnels in the country are the 30- by 60-foot tunnel at Langley which is limited to a top speed of about 100 knots and the 40- by 80-foot tunnel at the Ames Research Center with a 200-knot speed capability. These tunnels, particularly the latter, have been quite valuable for the large-scale investigations of conventional airplanes. However, even the 40- by 80-foot wind tunnel is quite limited when it comes to test and development work on V/STOL aircraft. There is no facility anywhere which approaches the capability to test large tilt rotors for instance in the 300- to 400-knot speed range where their problems exist.

Such a superfacility would require power equivalent to that in the Forrestal class carriers (several hundred thousand horsepower) and would cost an equivalent amount of money. There is insufficient justification on the basis of the V/STOL problem areas alone to justify such a major project. There are, however, needs for a high Reynolds number, high Mach number facility for conventional aircraft development (ref. 47) as well as the desire for a high Reynolds number transonic facility for studies of the aerodynamic loads on space boosters. Together these may provide sufficient justification.

Future Application of V/STOL Technology

As indicated in the introduction, one problem delaying the application of V/STOL technology appears to be that of properly identifying the mission for which V/STOL aircraft are most suited. Perhaps too much attention has been directed toward trying to invent a better configuration and not enough at looking at the transportation problems that exist. The following two suggestions are not intended as final answers, but merely as examples of a different approach that may be taken.

The white hope of V/STOL aircraft in commercial transportation is to be able to bring the passenger closer to his intended destination. One problem that exists today, however, is that very few people want to go to the so-called center of the city. The commerce of the city is moving out to suburbs and spreading over the entire city. There are many conventional airports that are almost as well located under these circumstances as could be hoped for - Washington National, Laguardia, Midway, Love, and Lindberg Field, for example. The advent of the jet transports with their longer take-off distances and noise problem has tended to put these airports in jeopardy. Washington National was only recently opened to jets and then only to the short-haul variety that could operate from its short runways. Perhaps an attempt should be made to apply existing V/STOL technology to developing aircraft that would keep these airports in operation. What would the requirements of such aircraft have to be? They would not have to take-off and land vertically. Even a modest STOL capability would suffice. The aircraft would have to be able to take-off and land in field lengths appreciably shorter than the length of the existing runways - say operational field lengths of the order of 3,000 feet - and be able to make steep climb-outs and steep landing approaches to minimize the noise problem. It would have to be designed to suppress the noise to the maximum extent possible at its source. This could mean using high-bypass-ratio engines (for low exhaust velocities) designed for low noise, submerged in acoustically treated ducts to contain the fan noise. With the steadily increasing demand for air transportation, it would have to be a large aircraft (capable of handling 200 or so passengers).

Figure 39 shows one approach that may be taken. The demand for short-take-off-and-landing performance and steep climb and descent paths in an economical airplane without putting in excess power requires distributing the propulsion across the span of the wing to a considerable extent. This suggests the application of the internal-flow jet-flap principle initially proposed about 10 years ago (ref. 48) but utilizing high-bypass-ratio engines to minimize the temperature and noise problem associated with the power plants that were available at that time. The concept proposed in figure 39 points out one additional problem area in the general V/STOL area; that is, the problems of operating many power units. A considerable amount of work has been done in the area of lift engines to minimize the cost and complexity of multiple-engine units. Also the auxiliary power unit on today's transport aircraft operates with relatively little attention. Some of this technology along with considerable ingenuity would have to be applied to solve the engine management, maintenance, and costs problems of the multiple engines in the aircraft shown. Such an aircraft might employ about twenty 5,000-pound-thrust, high-bypass-ratio engines, a thrust-weight ratio of the order of one-third and wing loadings comparable to conventional jet transport aircraft.

Another approach to the application of V/STOL technology can be arrived at by taking off from thinking about the revived interest in ground transportation. Studies of high-speed ground transportation soon reveal the fact that the cost of the right of way and guideway is the predominant cost item. The most economical system on all except the most heavily traveled routes will be the system with the least expensive guideway. The guideway is to serve two purposes: to support the vehicle and to guide it so that the traffic control problem becomes a one-dimensional problem of providing separation between vehicles in line. Operation on the guideways permits bringing the vehicles to a stop, if necessary, to preserve the separation. What means other than steel rails and flanged wheels can be used for the purposes of support and guidance? Support of the vehicle can be supplied by V/STOL technology; using wings for cruising flight and rotors or fans if the vehicle must be slowed or stopped. This eliminates the most expensive part of the guideway by eliminating the structure which has to be strong enough to support the weight of the vehicle regardless of whether the vehicle is present. But how about guidance? Present air traffic control systems do not provide the tight guideway system. The vehicle does not have to actually contact a rail for tight guidance. Leader cables are being investigated experimentally for the terminal landings of aircraft and for the guidance of automobiles on automatic highways. It would appear that something similar could be developed from the rapidly developing electronics field to provide reasonably tight guidance over reasonable distances for high-density traffic systems. Figure 40 is a crude sketch intended to depict the type of system envisioned. Electronic techniques would provide the guideway and vehicle separation along the guideway. This is, of course, the simplest form. Cross-overs and switching techniques would have to be developed. This line of thinking merely suggests the possibility of a fully automated transportation system that might evolve through further study using a marriage of V/STOL and electronic technology.

CONCLUDING REMARKS

This paper has attempted to touch on some of the primary, and some not so primary, areas in V/STOL technology requiring further attention. There are many areas where additional work will lead to performance improvements and enhance the reliability. In some cases, such as the stopped rotor and tilt rotor, additional work including flight demonstrations, will be required before a full assessment of the problems of the type can be made.

As indicated in the introduction, the primary need is probably that of identifying the mission to which V/STOL aircraft should be designed. In this regard, work on the noise reduction, traffic control, and instrument flight problems appears most important inasmuch as the extent to which these problems can be minimized will greatly affect any assessment of the missions for which V/STOL aircraft should be designed.

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SYMBOLS

AR	wing aspect ratio
b	wing span, ft
C_f	effective skin-friction coefficient
C_{L_∞}	lift coefficient out of ground effect
D_∞	drag out of ground effect, lb
ΔD	drag increment, lb
D_e	effective diameter, ft
e	span efficiency factor
h	height above ground, ft
$h_{c/4}$	height of wing quarter-chord point above ground, ft
L_∞	lift out of ground effect, lb
ΔL	lift increment, lb
ΔL_g	lift increment due to ground effect, lb
ΔL_b	lift increment due to base loss, lb
$(L/D)_{max}$	maximum value of lift-drag ratio
M_x	rolling moment, ft-lb
ΔM	pitching-moment increment, ft-lb
n	fan rotational speed, rev/sec
p/p_a	fan pressure ratio
R_∞	resultant force out of ground effect, lb
R_G	resultant force in ground effect, lb
r	radial distance, ft
S	wing area, ft^2

S_{wet}	wetted surface area, ft^2
SHP	shaft horsepower, hp
SFC	specific fuel consumption, lb/lb/hr
T	thrust, lb
V_o, V_∞	free-stream velocity, ft/sec
V'	local velocity through fan, ft/sec
V_R	resultant velocity relative to blade, ft/sec
W	weight, lb
X	distance along course, ft
Y	lateral displacement, ft
Z	vertical distance above ground, ft
α	angle of attack, deg
β	sideslip angle, deg
Λ	wing sweep angle, deg
σ	density ratio
$\ddot{\phi}$	angular acceleration in roll, rad/sec^2
ϕ	propeller pitch angle, deg
ψ	propeller yaw angle, deg

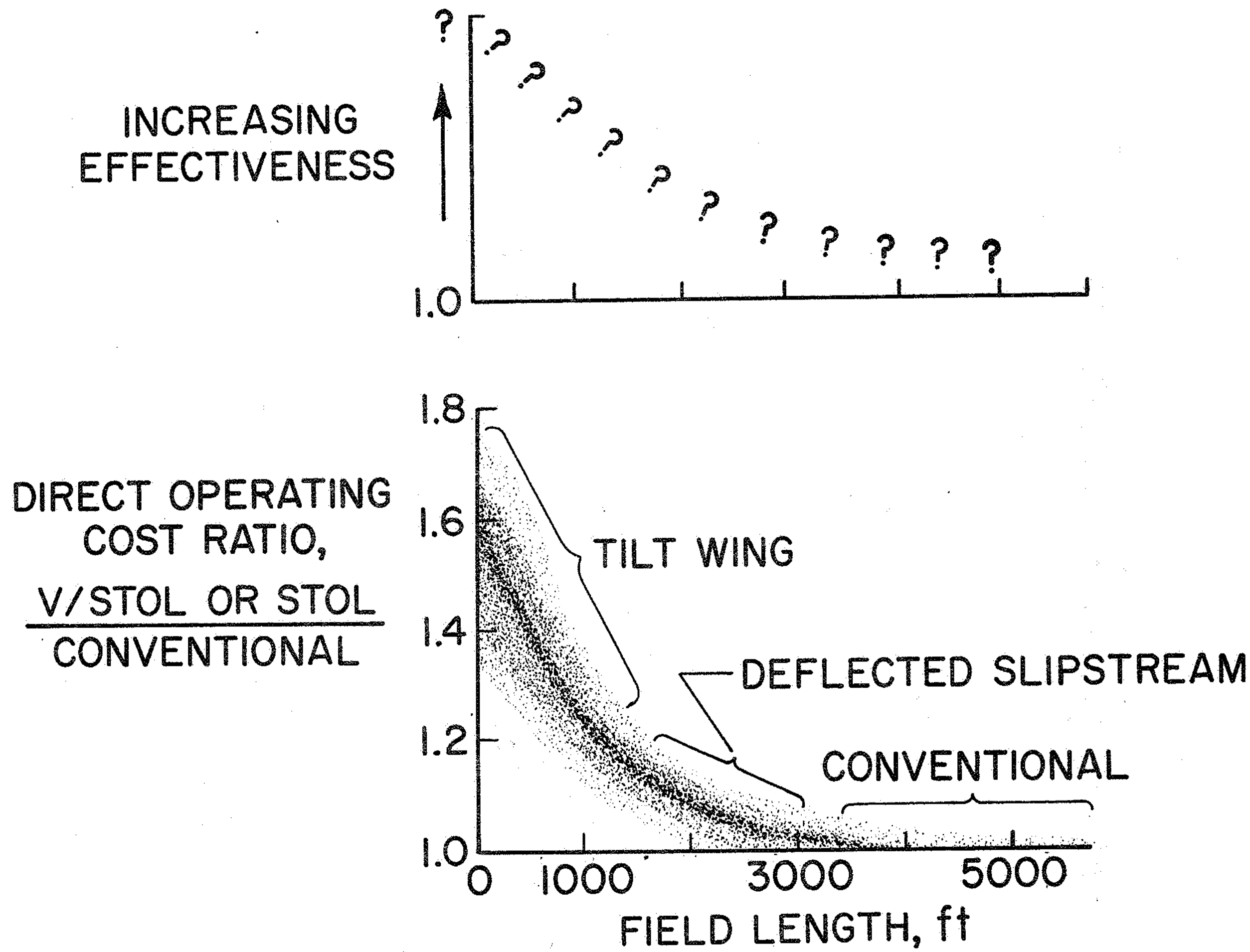


Figure 1.- Only the cost part of the cost effectiveness question has been answered to date.

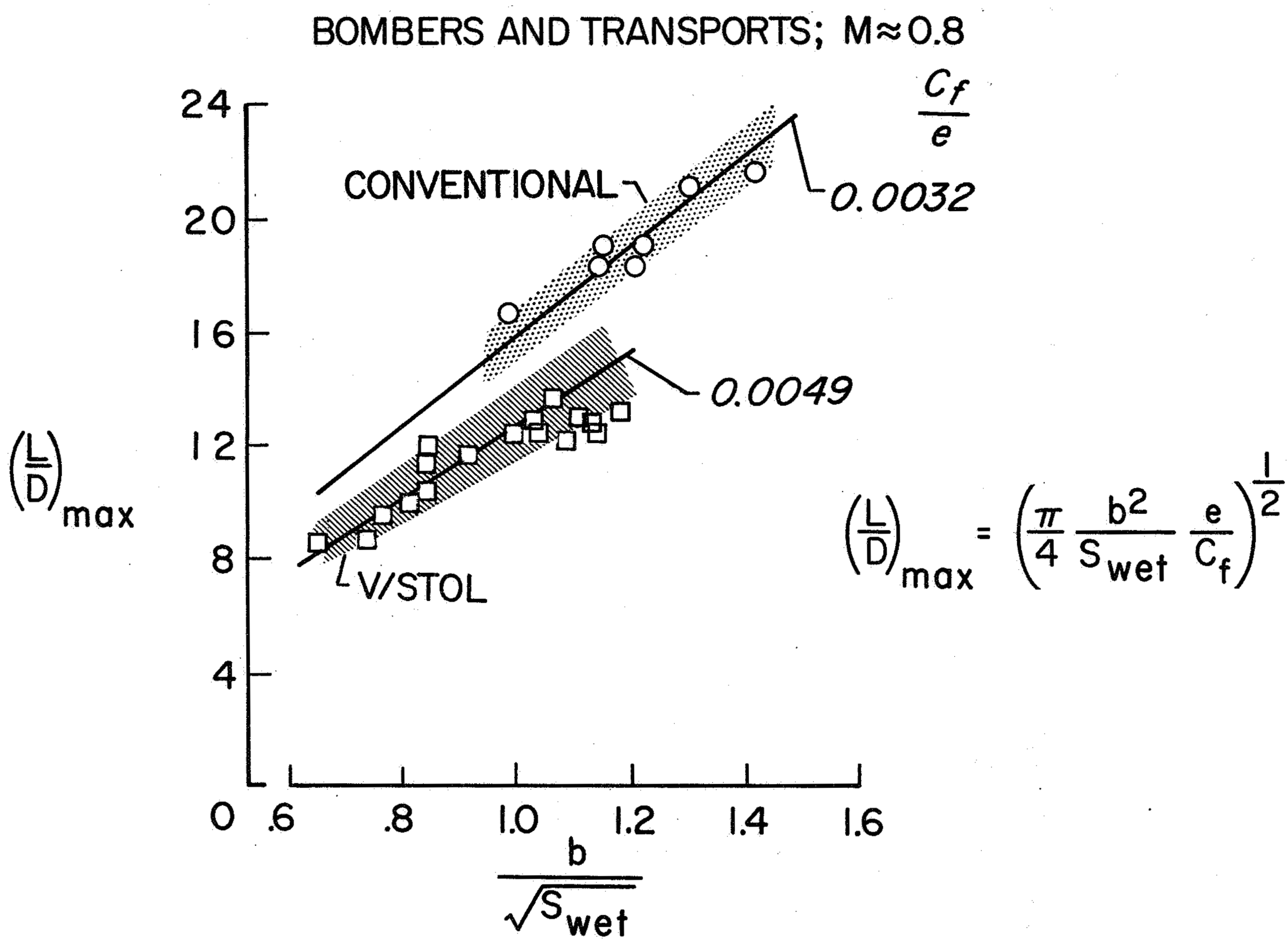


Figure 2.- Cruise performance of V/STOL transports.

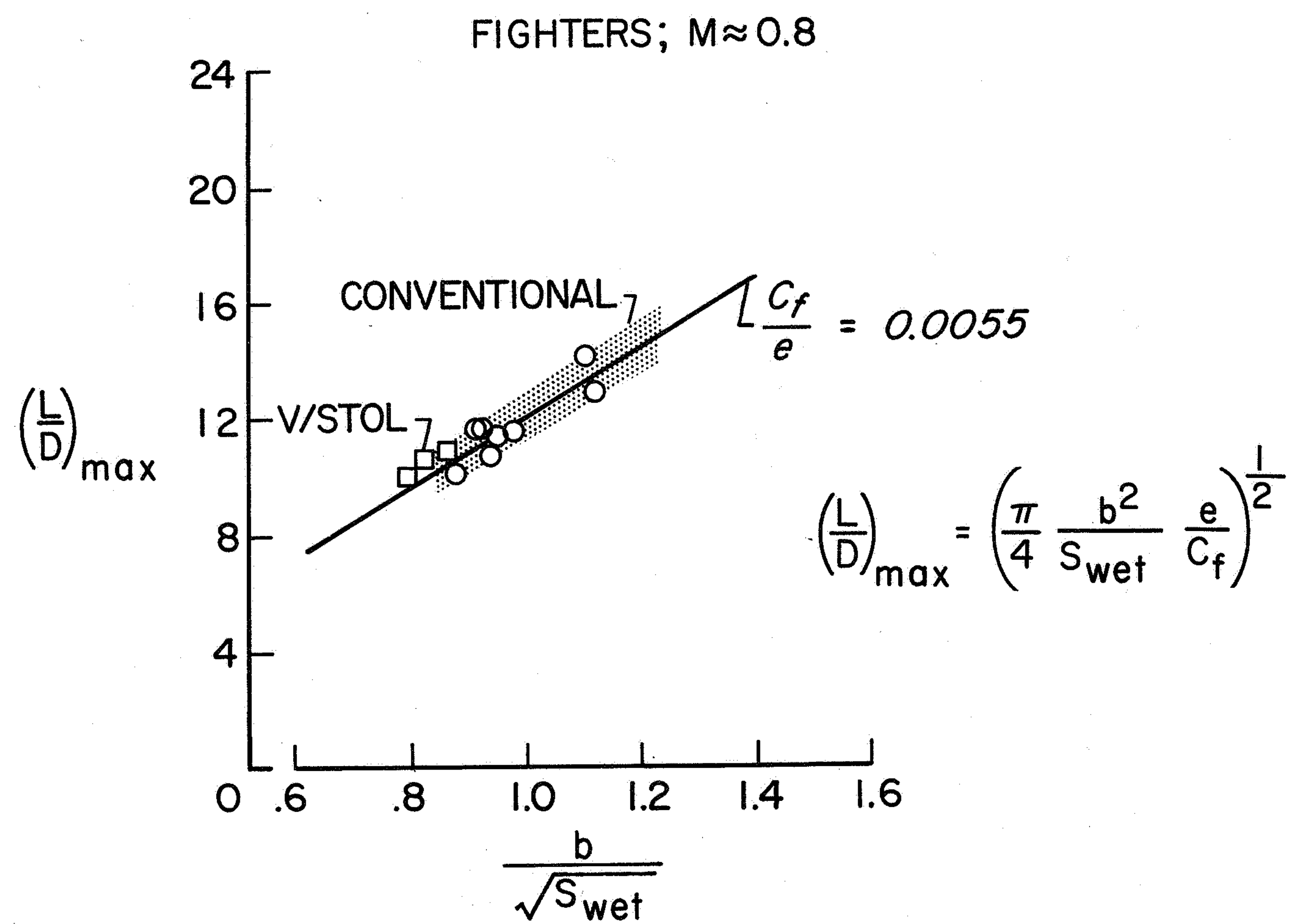


Figure 3.- V/STOL fighter shows aerodynamic cleanliness equal to conventional fighters.

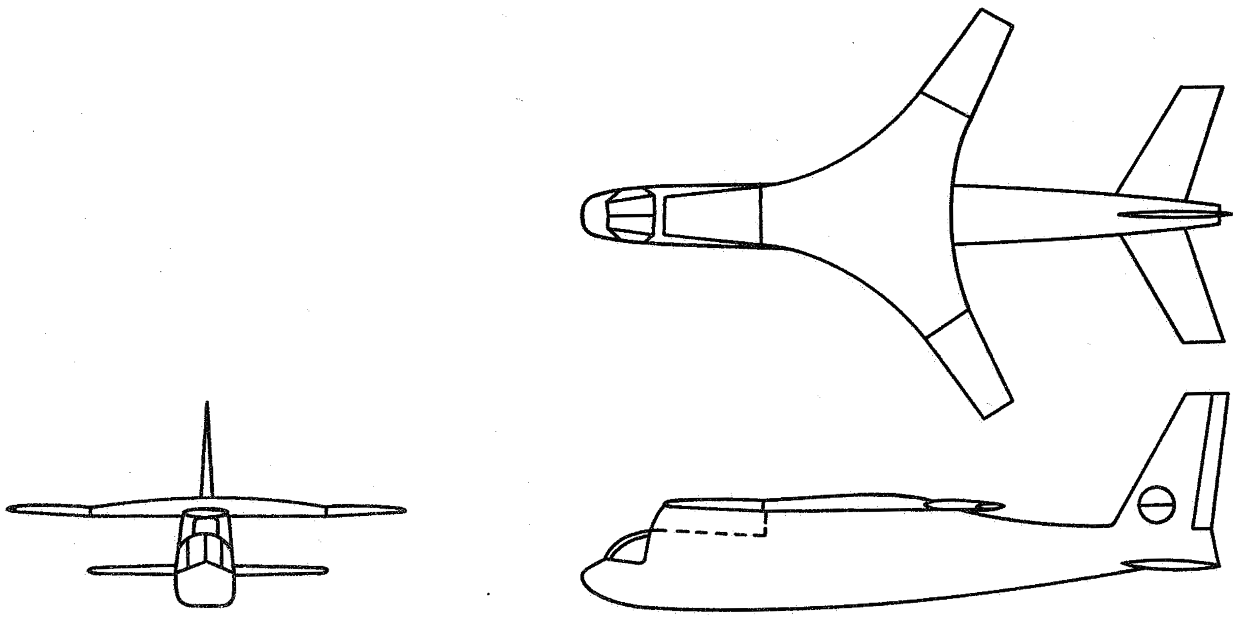


Figure 4.- Typical rotor-wing design.

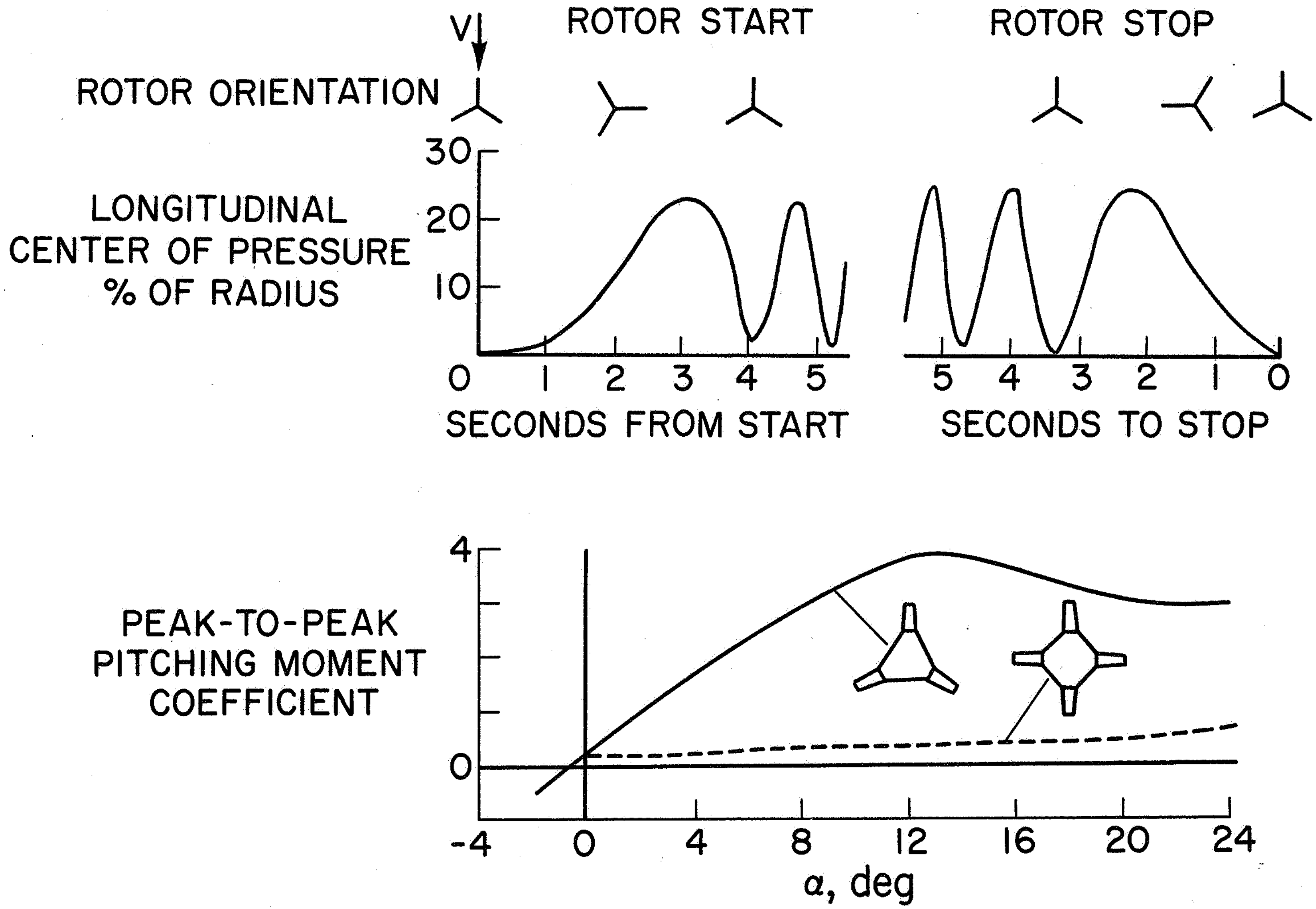


Figure 5.- Cyclic loads experienced by rotor-wing during conversion.

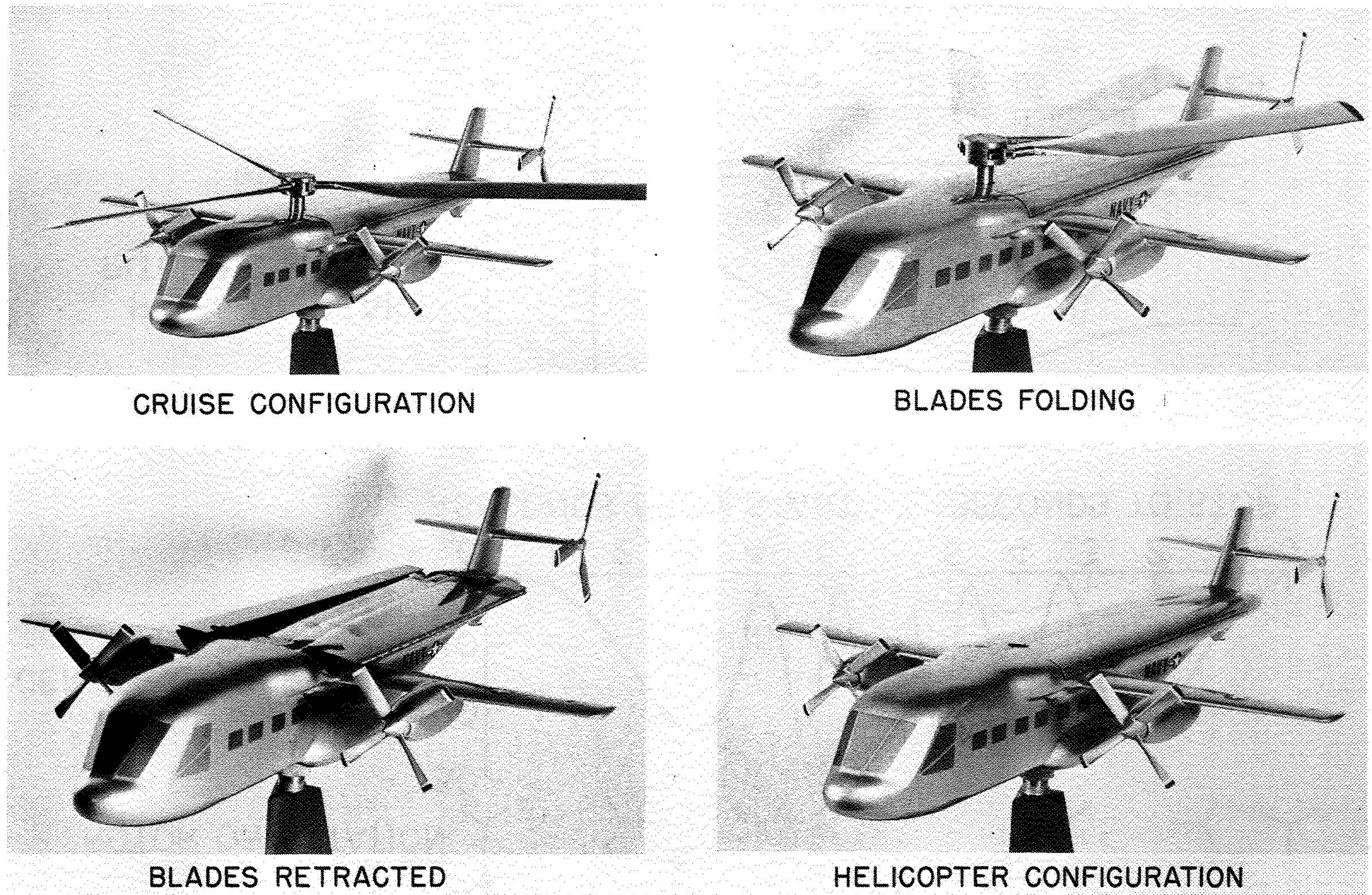


Figure 6.- One of the stowed rotor concepts. Photo courtesy of Lockheed.

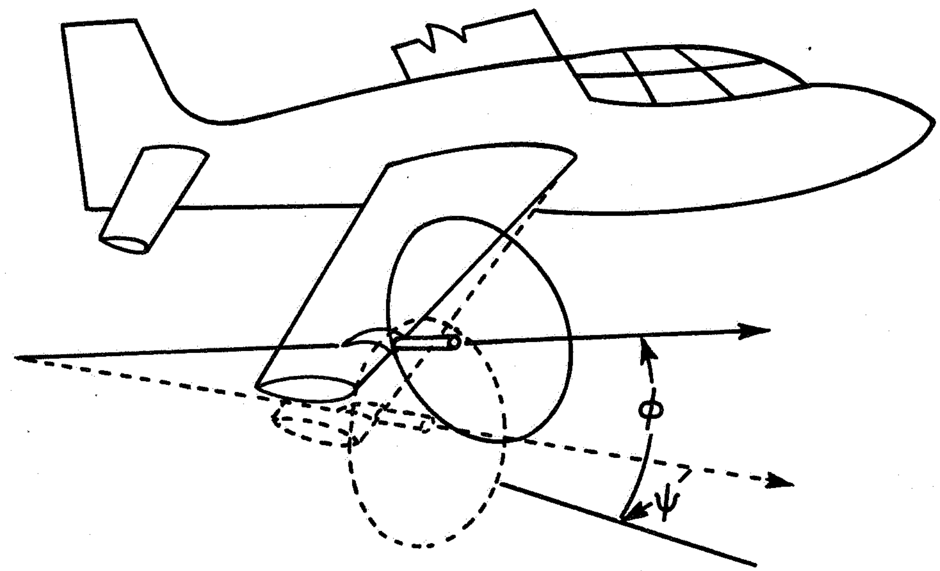


Figure 7.- The prop-rotor stability problem of the tilt-rotor concept is a more complex form of the whirl mode problem.

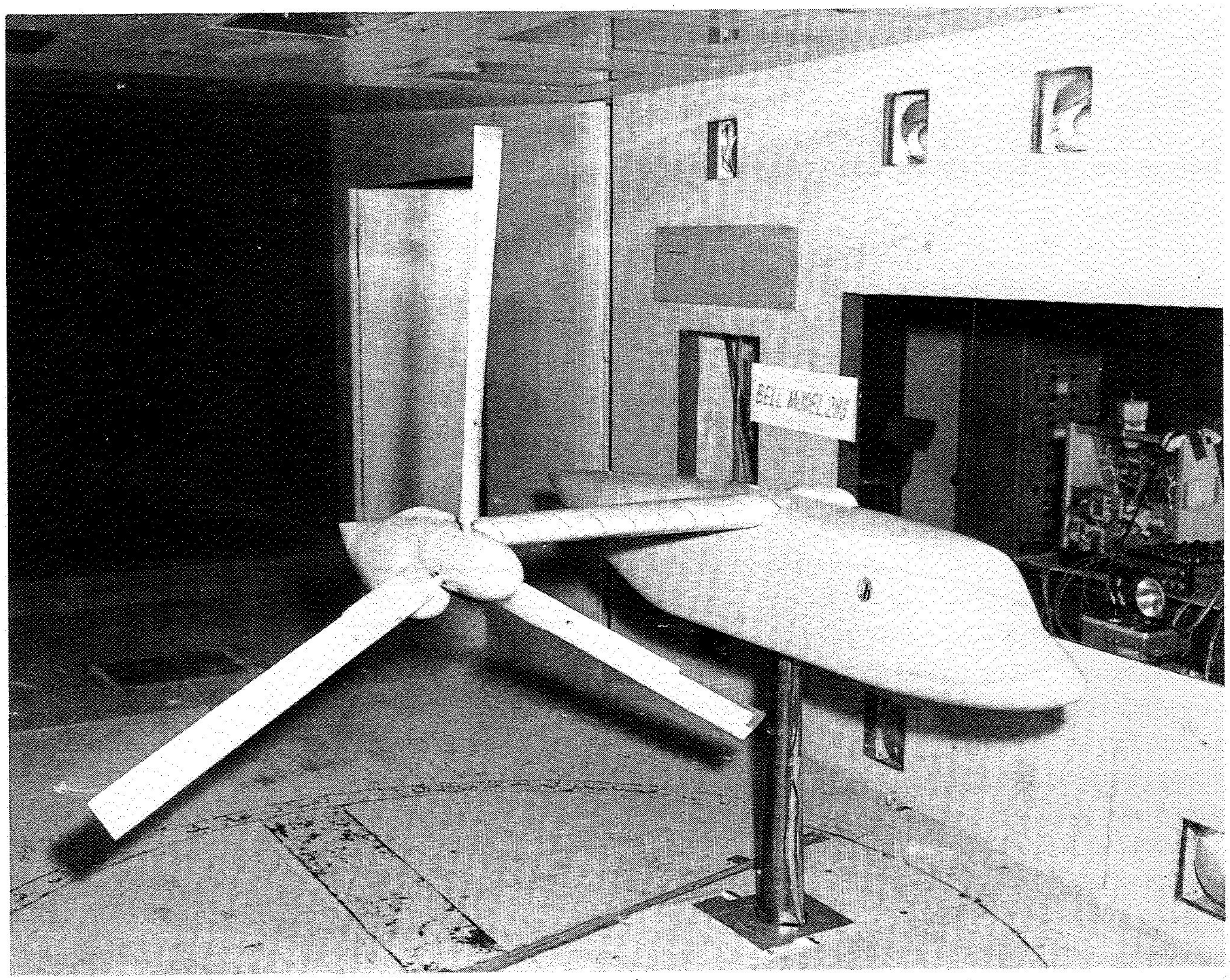


Figure 8.- Dynamic model used by Bell in prop-rotor stability studies. Photo courtesy of Bell Helicopter.

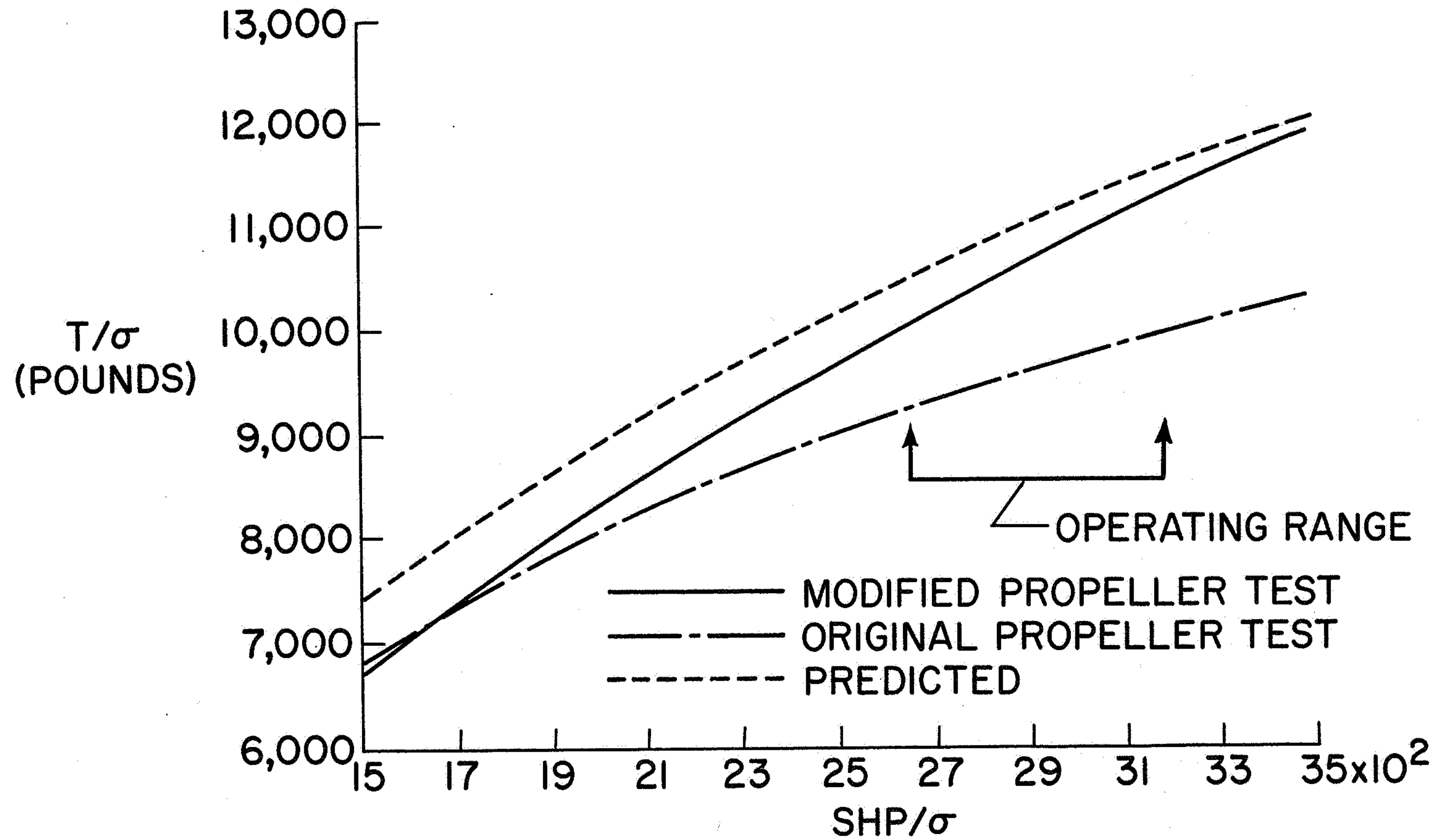


Figure 9.- Present methods of estimating static thrust are inadequate.

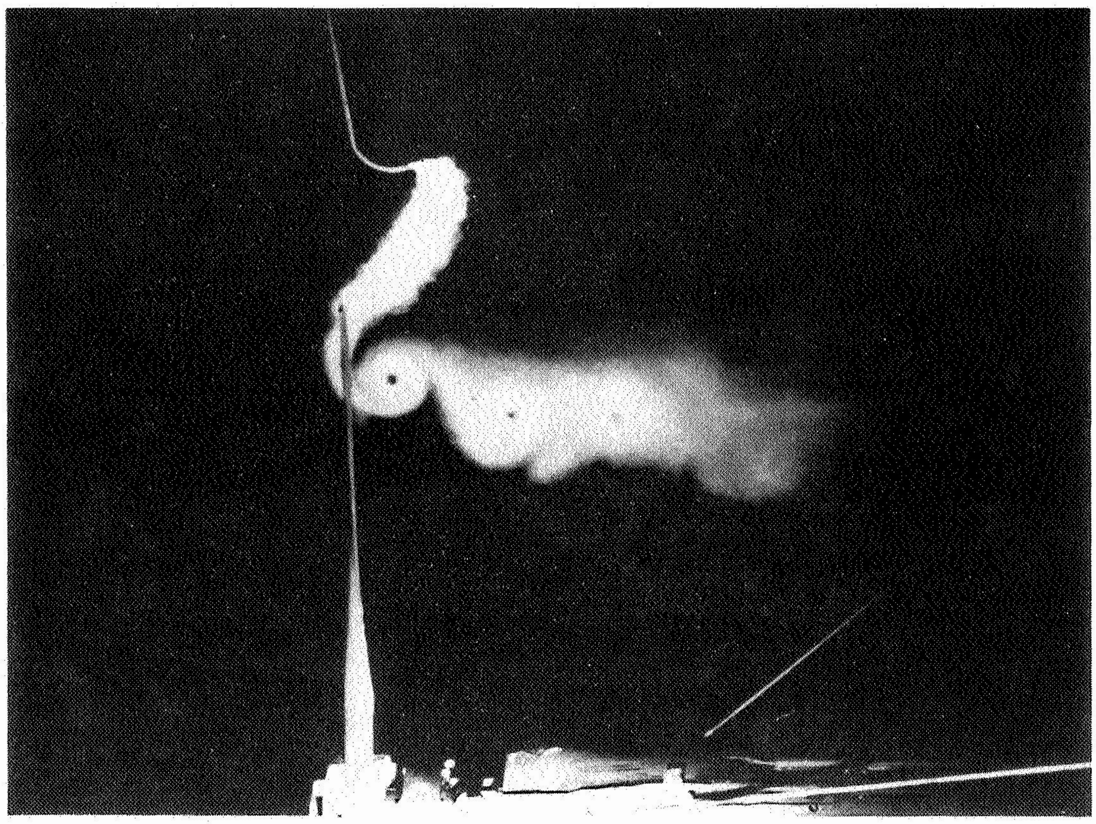


Figure 10.- Flow field at propeller blade tips under static conditions.

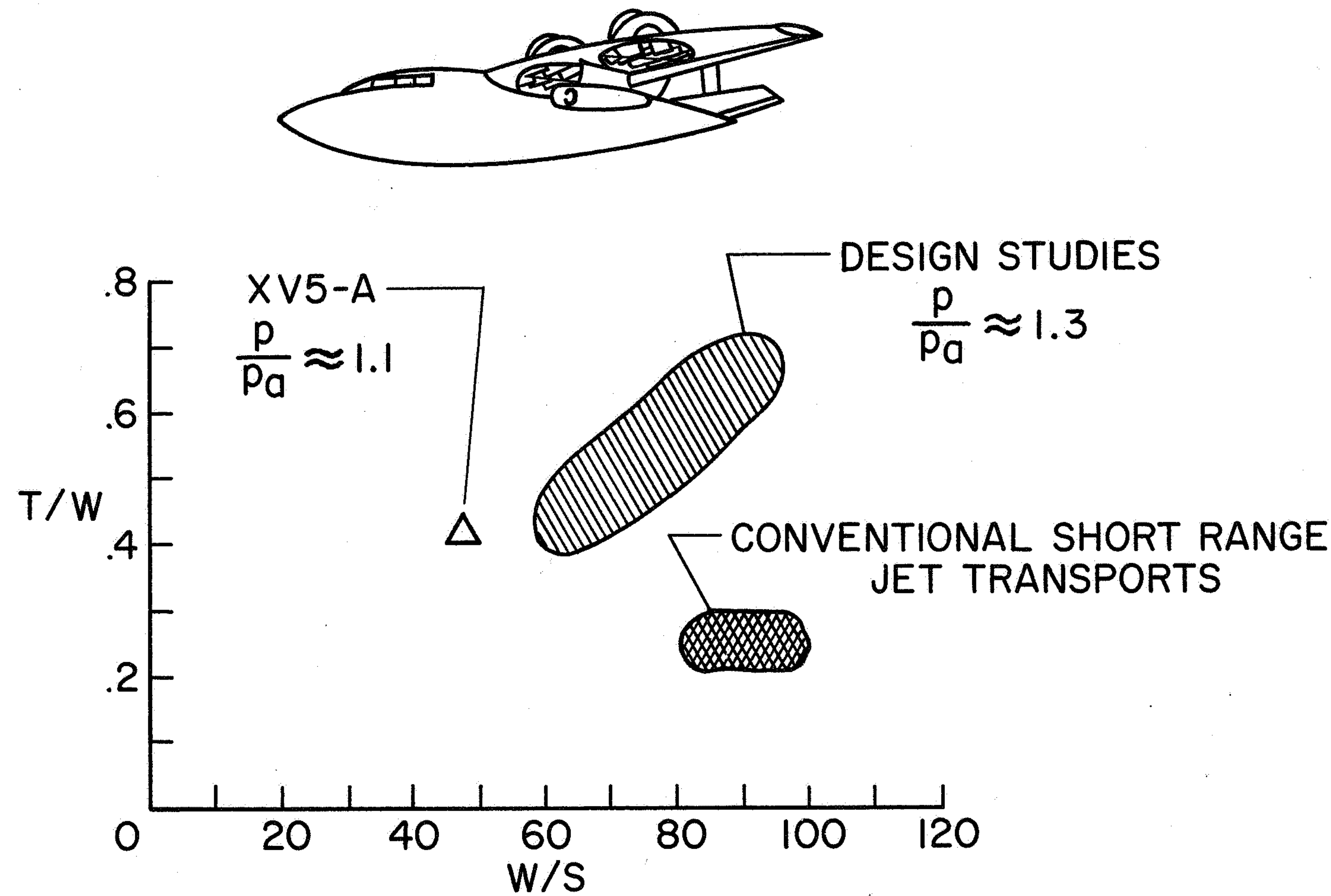


Figure 11.- Studies of fan-in-wing configurations show the need for high-pressure ratio fans.

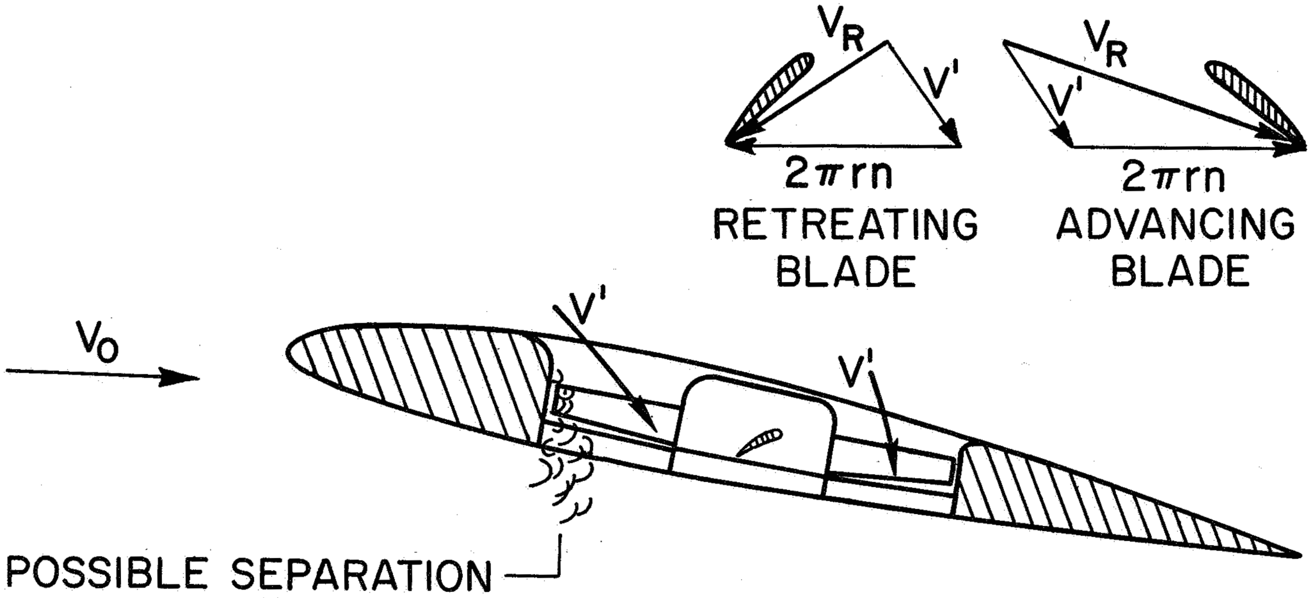


Figure 12.- Inlet flow distortion on fan-in-wing during transition.

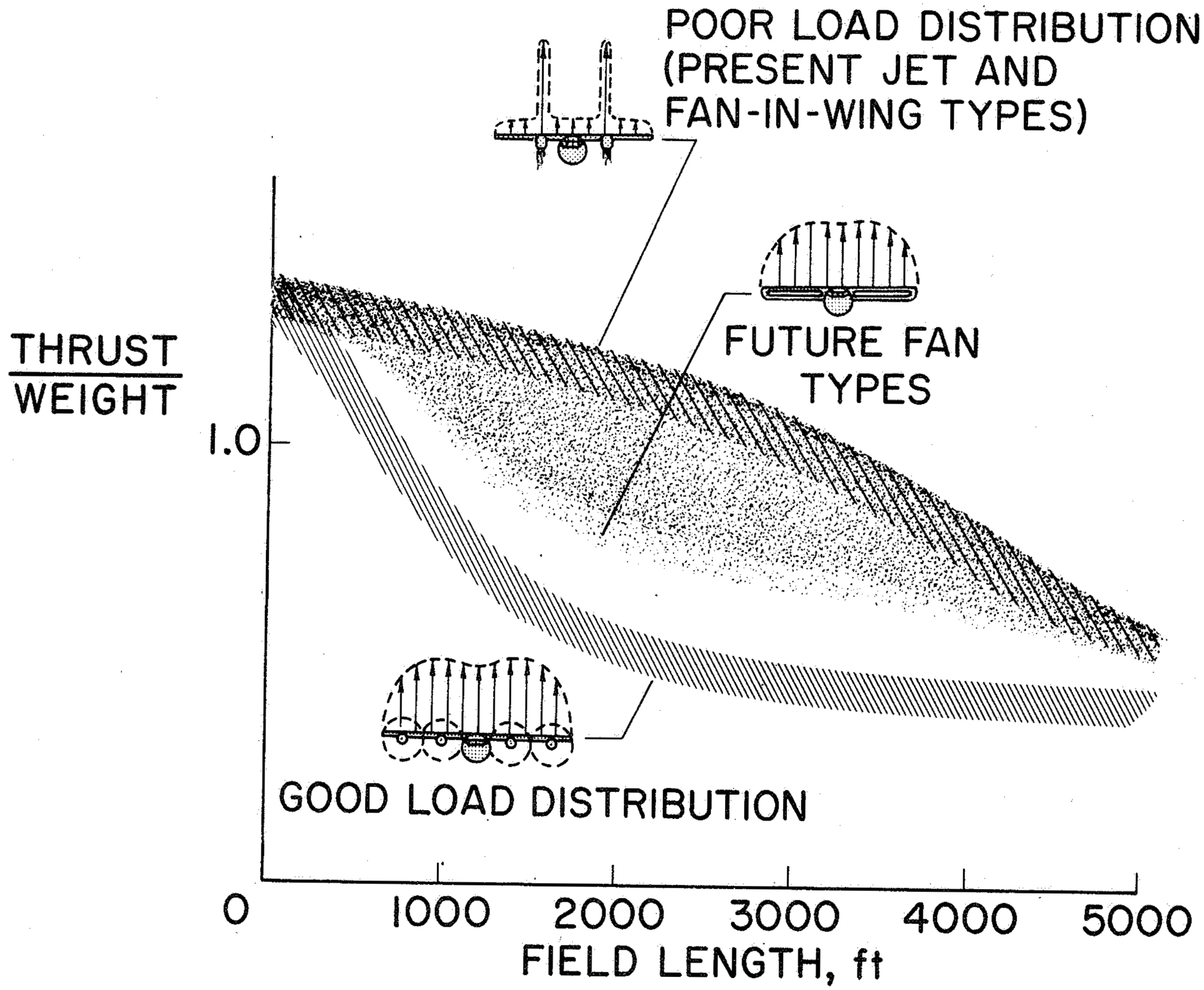


Figure 13.- Significant reduction in thrust required for STOL performance requires good load distribution and effective thrust vectoring.

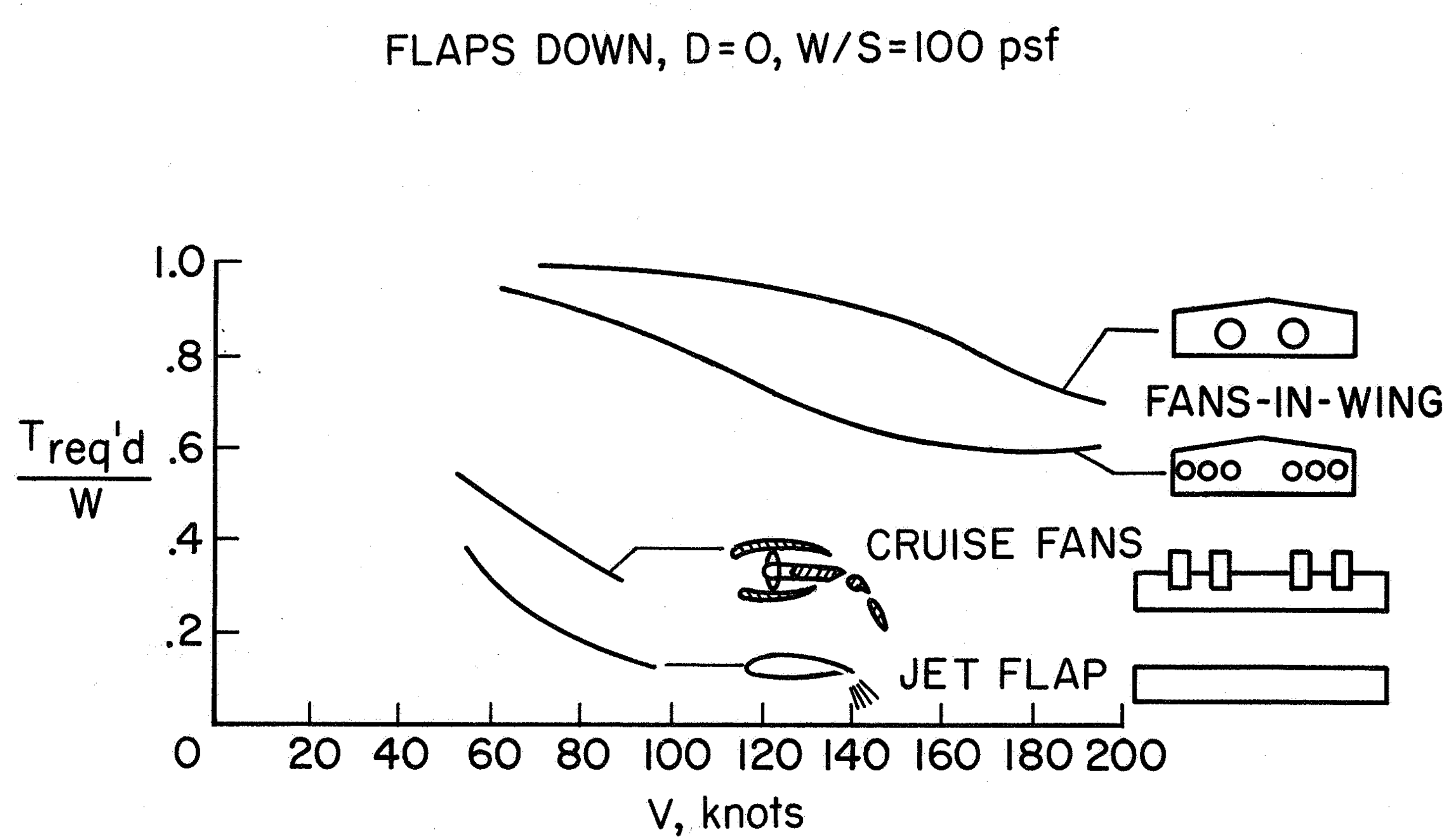


Figure 14.- Thrust required in level flight for several fan configurations.

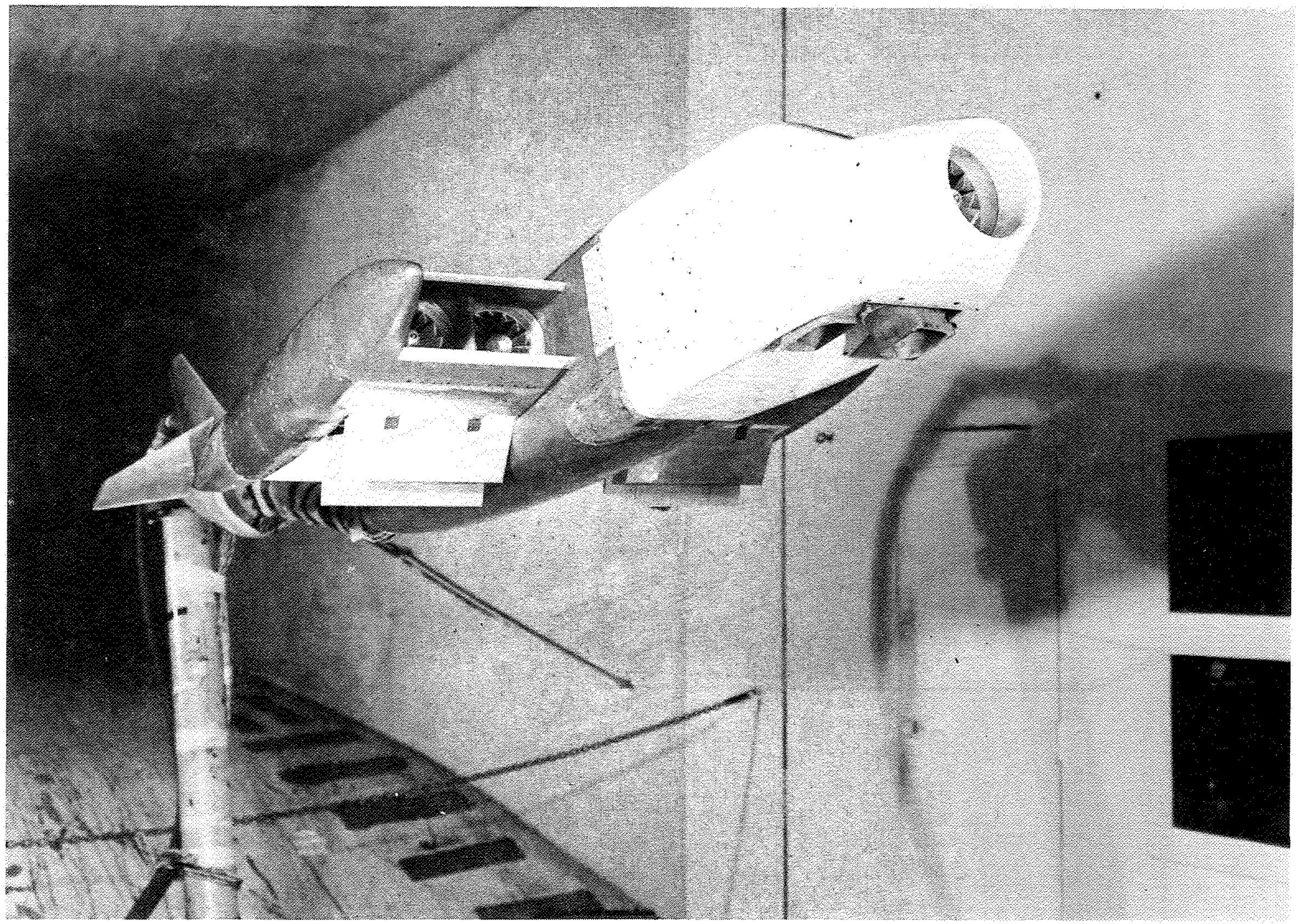


Figure 15.- Adam II model in 17-foot test section.

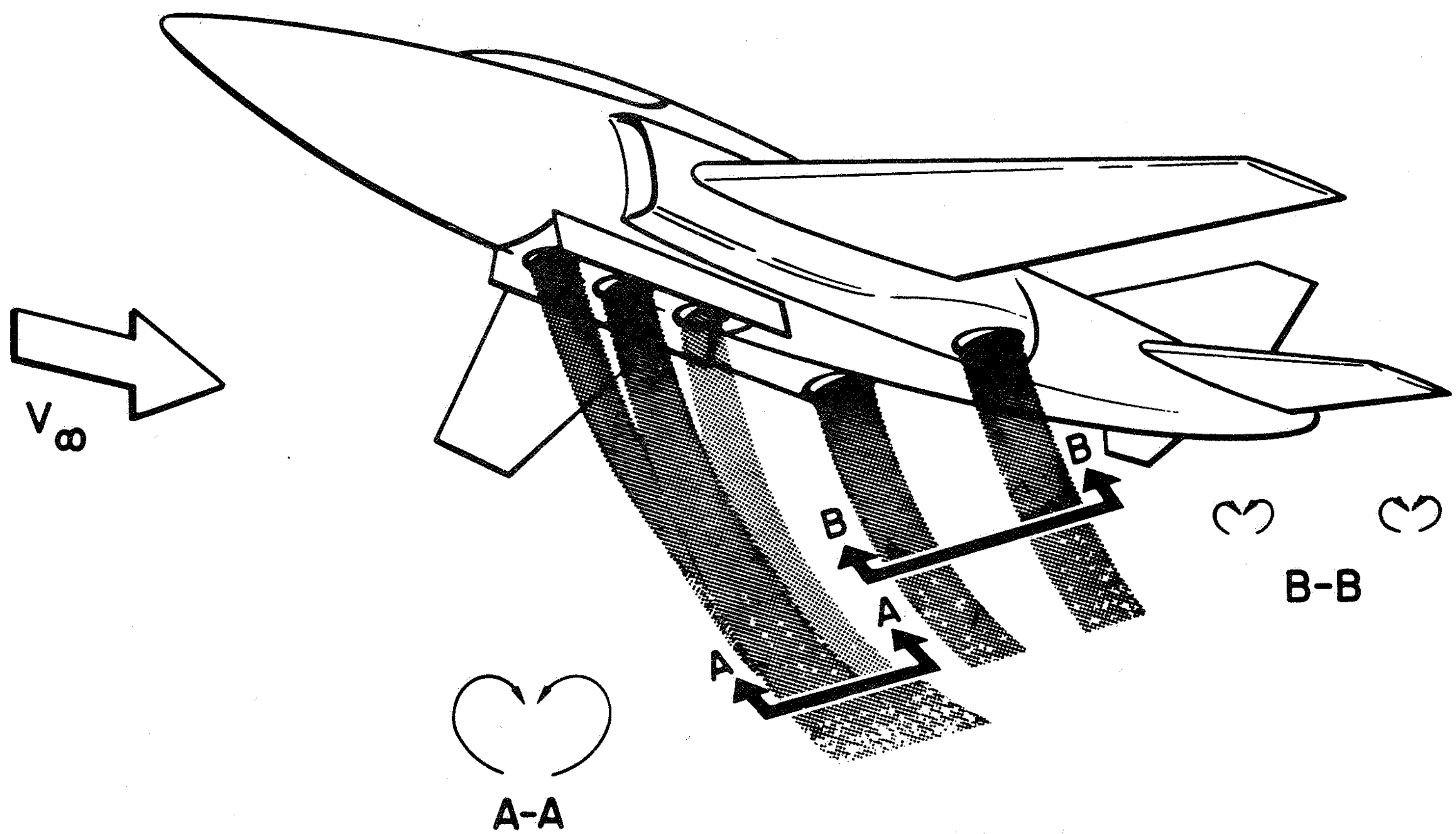


Figure 16.- Jet wakes in transition flight roll-up into vortex pairs.

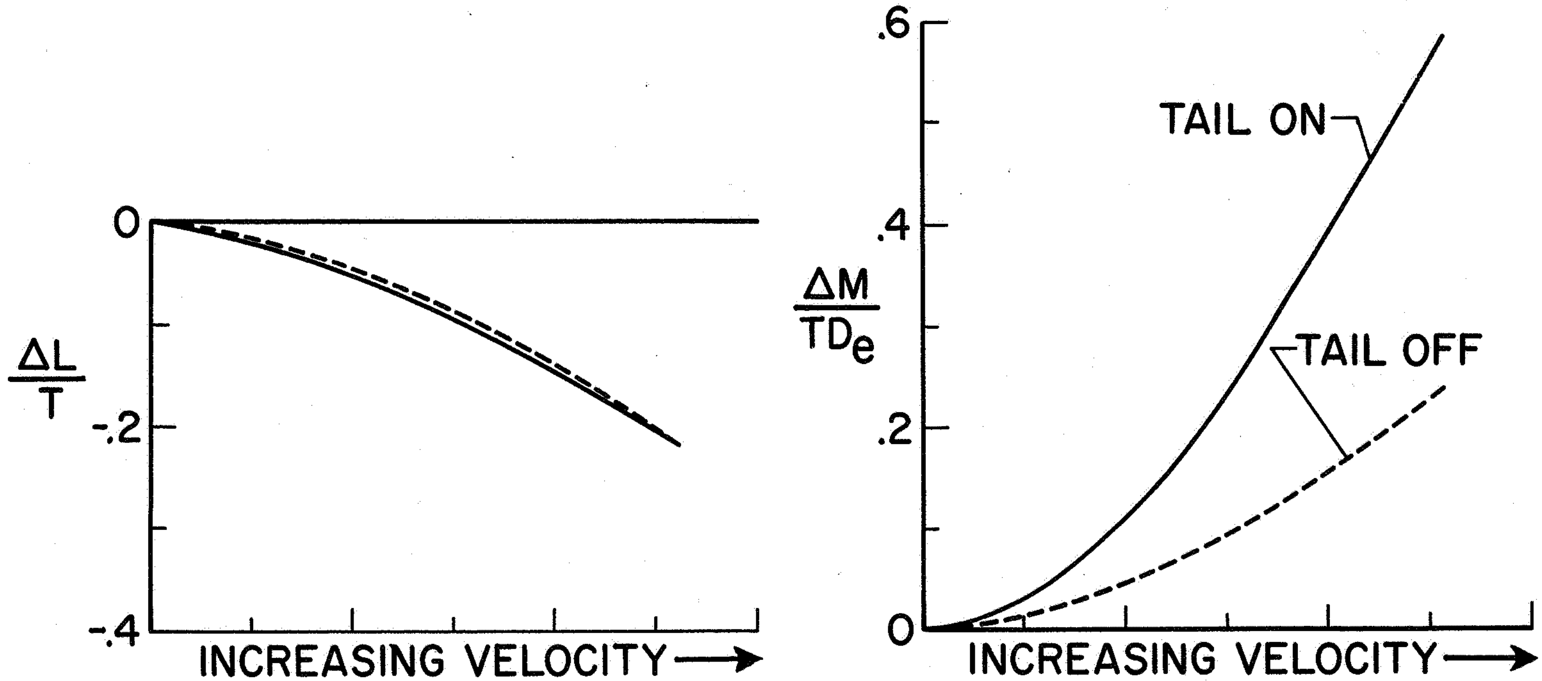


Figure 17.- Jet-induced lift loss and pitching moment.

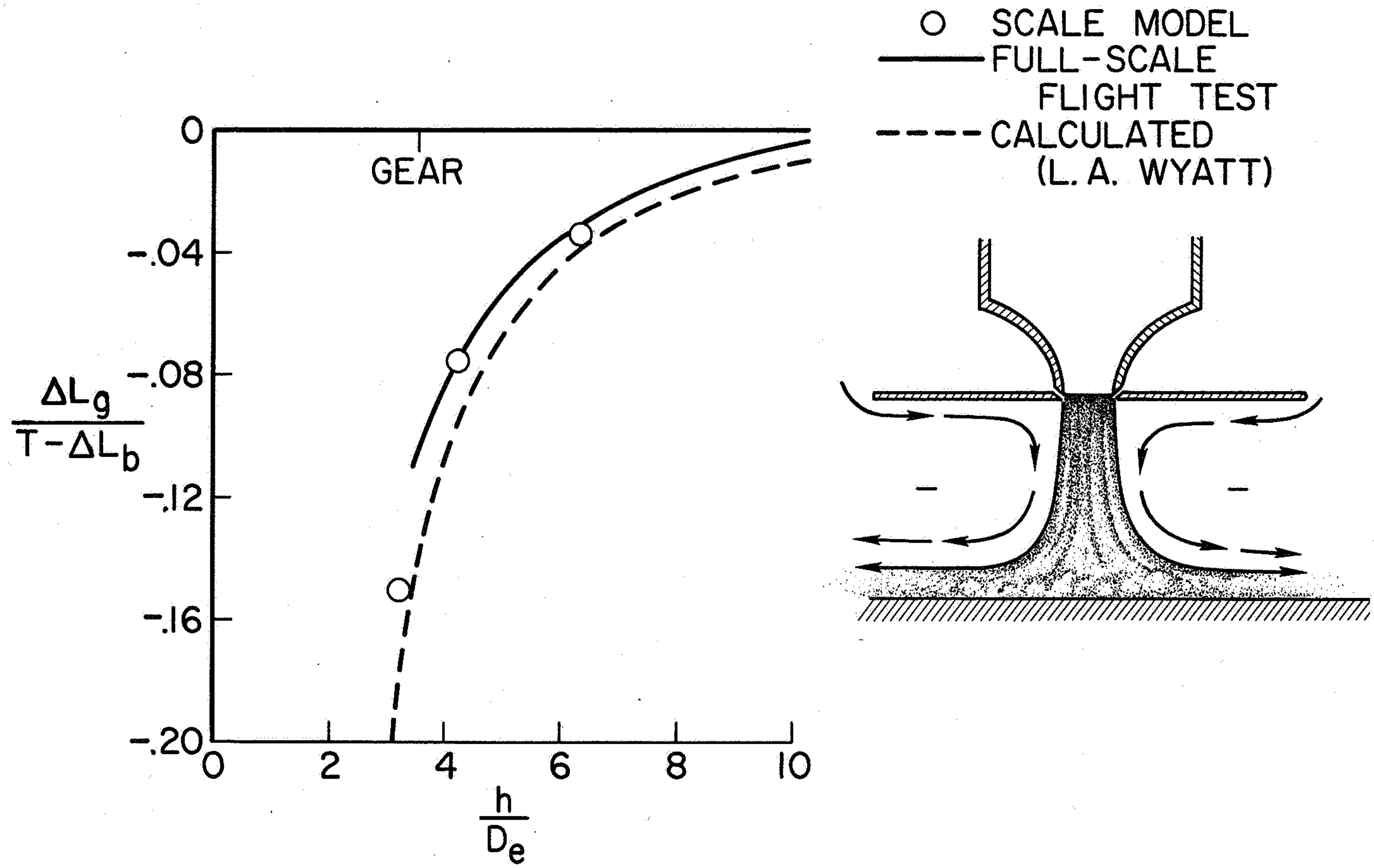
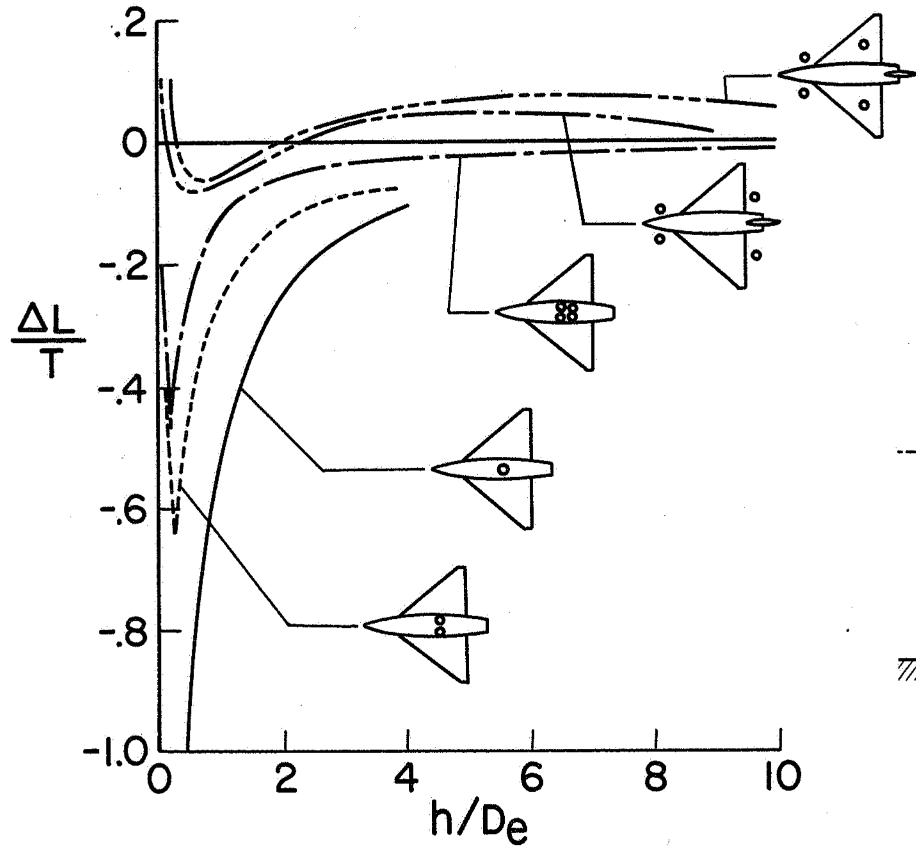


Figure 18.- Ground effect on single jet or closely spaced jet configurations can be calculated.



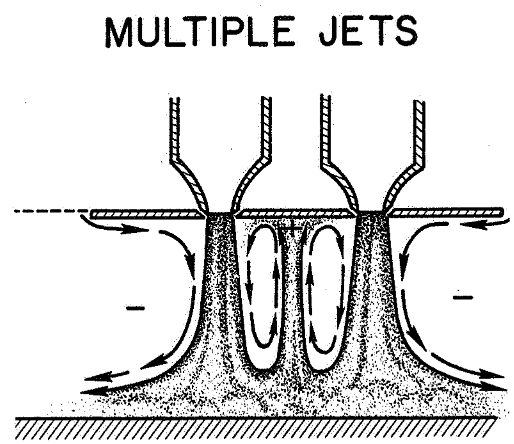


Figure 19.- Multijet arrangements reduce adverse ground effects but cannot be estimated.

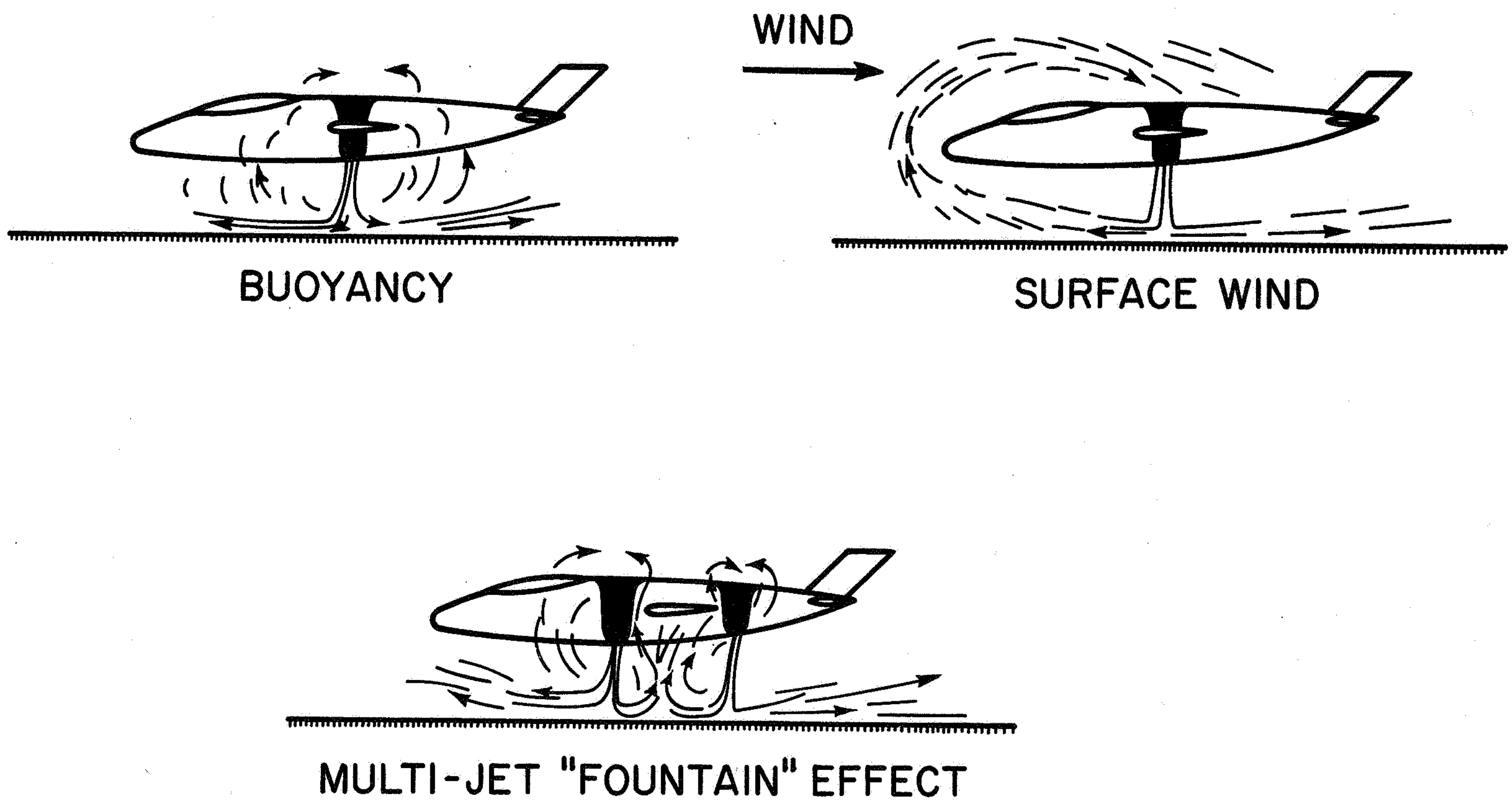


Figure 20.- Hot-gas ingestion causes thrust loss and compressor stall.

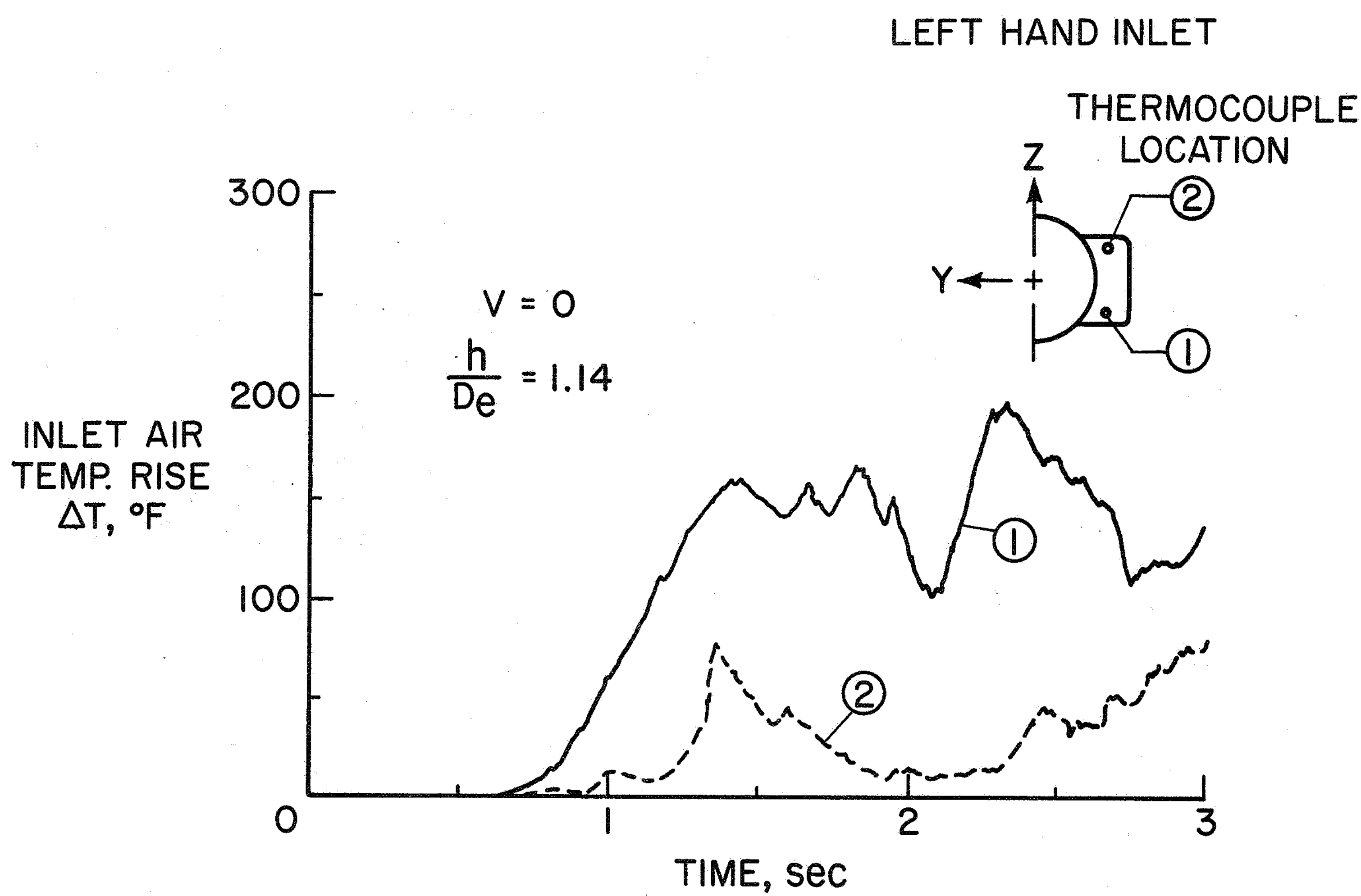
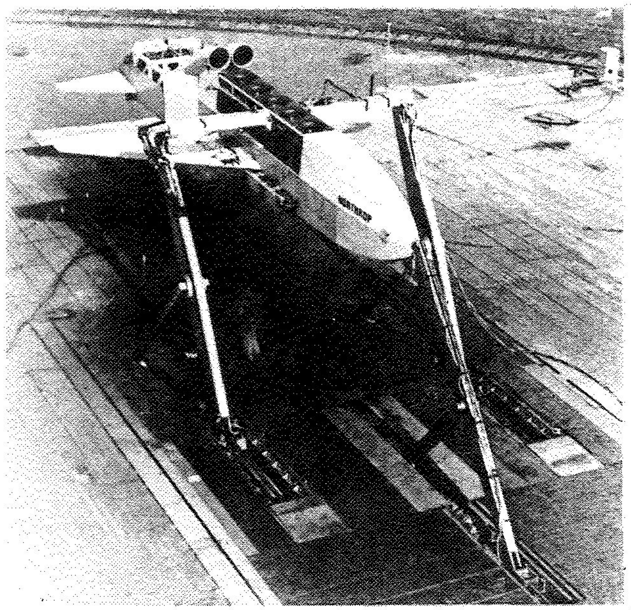


Figure 21.- Time history of inlet air temperature rise rectangular nozzle arrangement with forward-facing, side inlets.

AMES-NORTHROP
FULL-SCALE MODEL



LANGLEY
1/3 SCALE MODEL

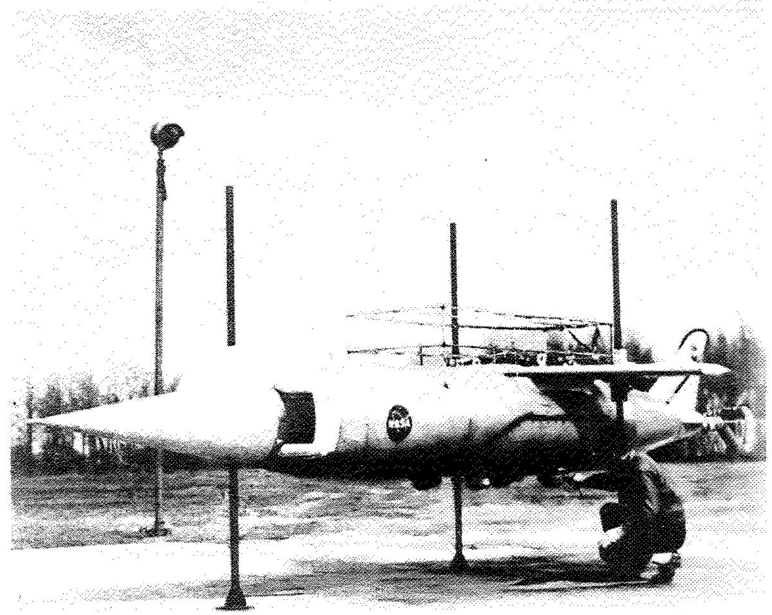


Figure 22.- Large-scale NASA models.

ENGINE DEVELOPMENT

HELICOPTER ENGINES

- INCREASE T.B.O.
  - DUST AND DEBRIS
  - TEMPERATURE CYLING
- REDUCE S.F.C.

FANS-IN-WING

- MINIMIZE CROSS FLOW EFFECTS

LIFT ENGINES

- INCREASE TOLERANCE TO INLET DISTORTION
  - PRESSURE
  - TEMPERATURE

VECTORED THRUST ENGINES

- DECREASE CRUISE S.F.C.

Figure 23.- Propulsion development areas requiring further attention.

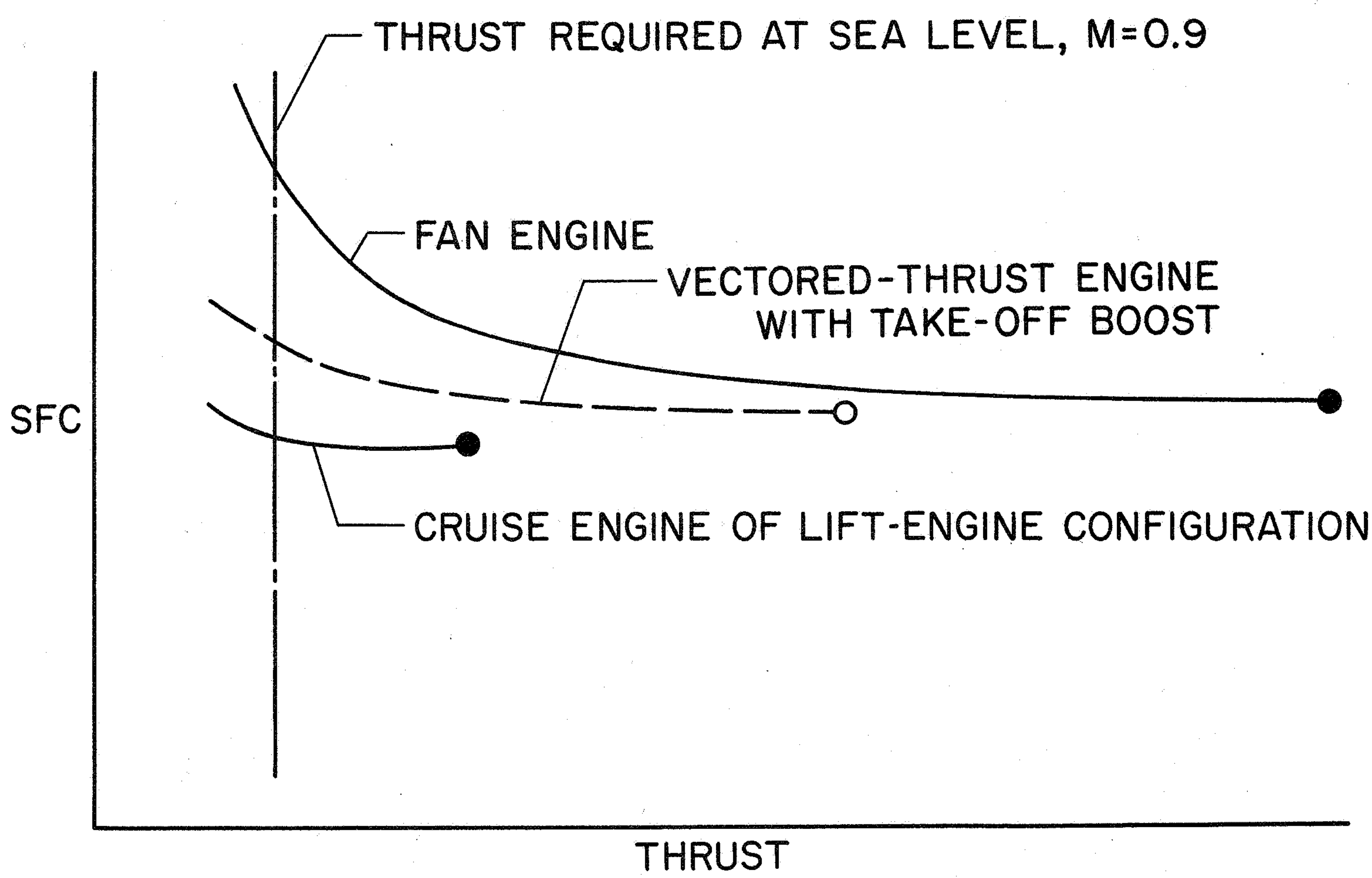


Figure 24.- The vectored-thrust engine mismatch problem can be reduced by using a take-off boost such as plenum chamber burning and by using variable-geometry features to increase the thrust of the fan section and decrease the hot-section thrust during part-power operation.

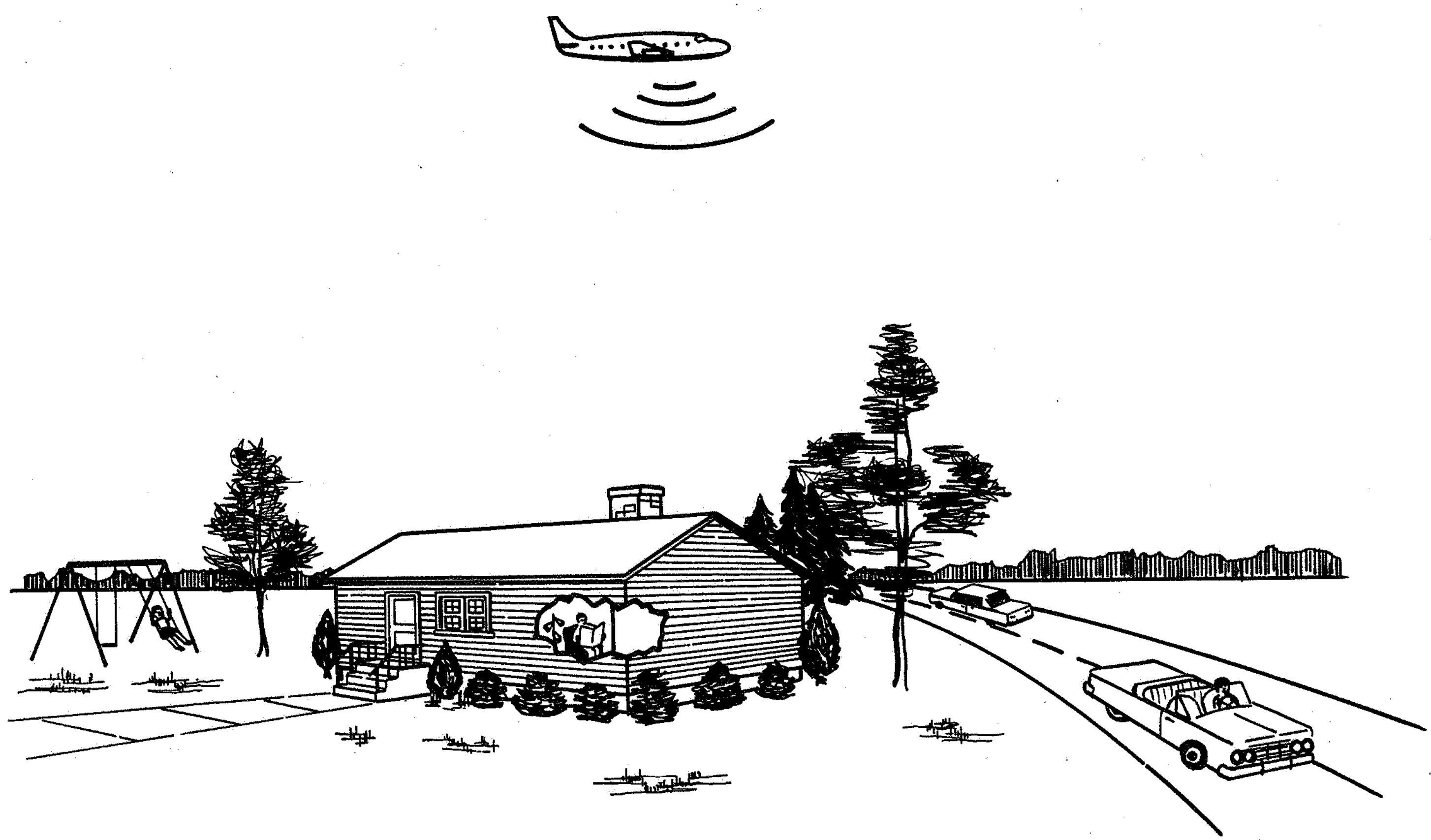


Figure 25.- Studies of human response to aircraft noise.

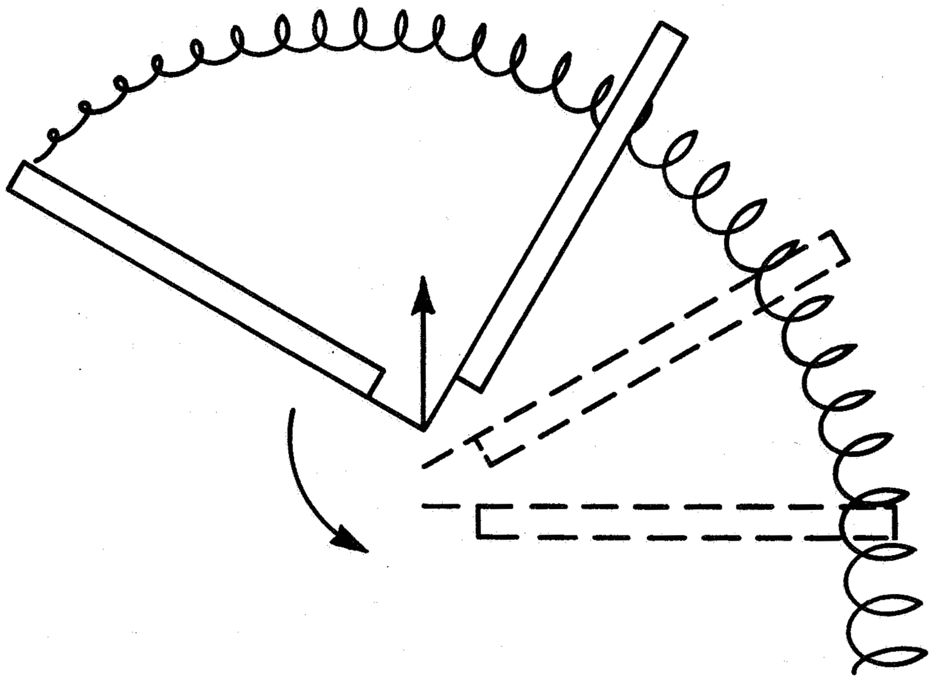


Figure 26.- The rotor "slap" is caused by blades intersecting the vortex from the preceding blade.

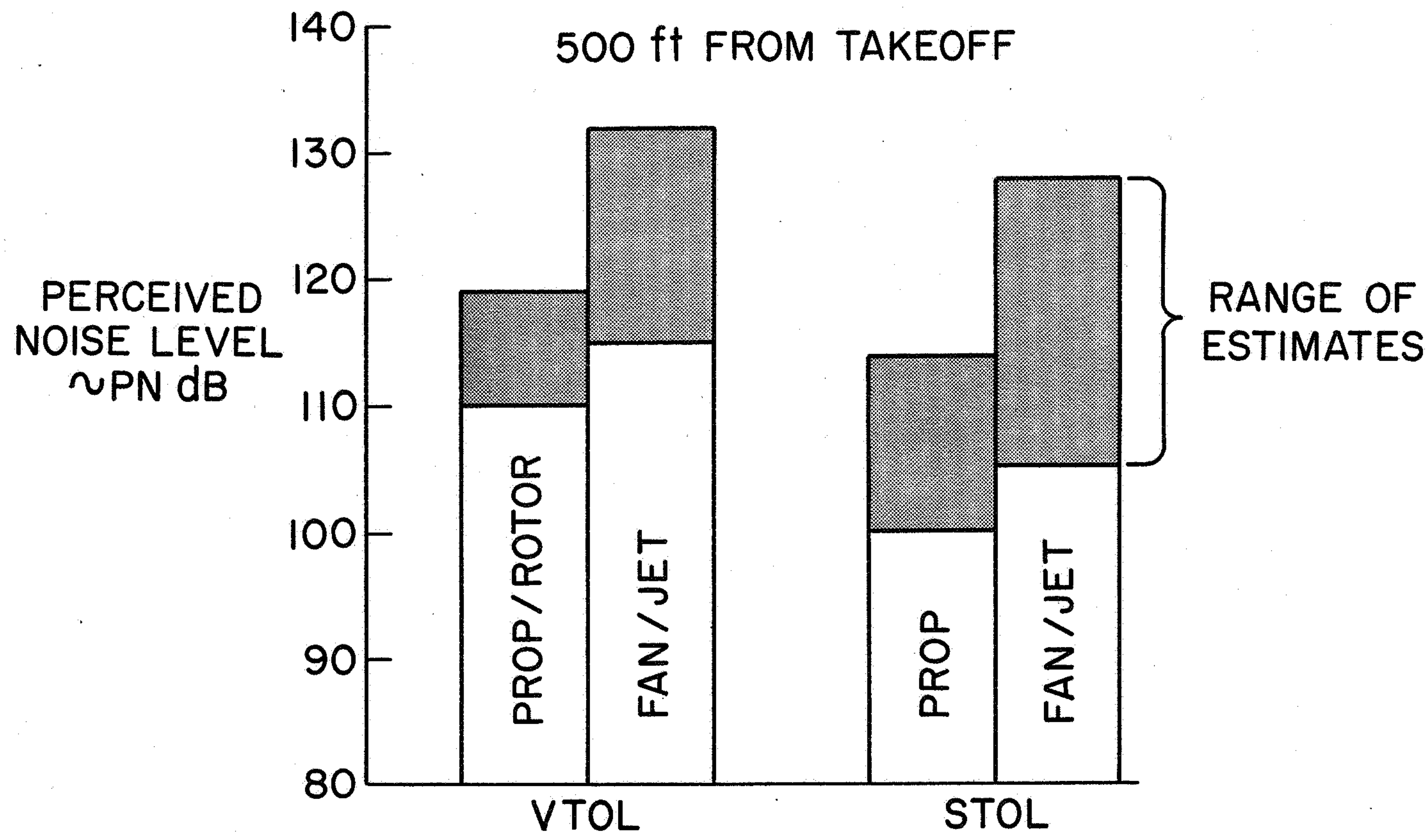


Figure 27.- Noise level has not been a primary consideration in designs to date.

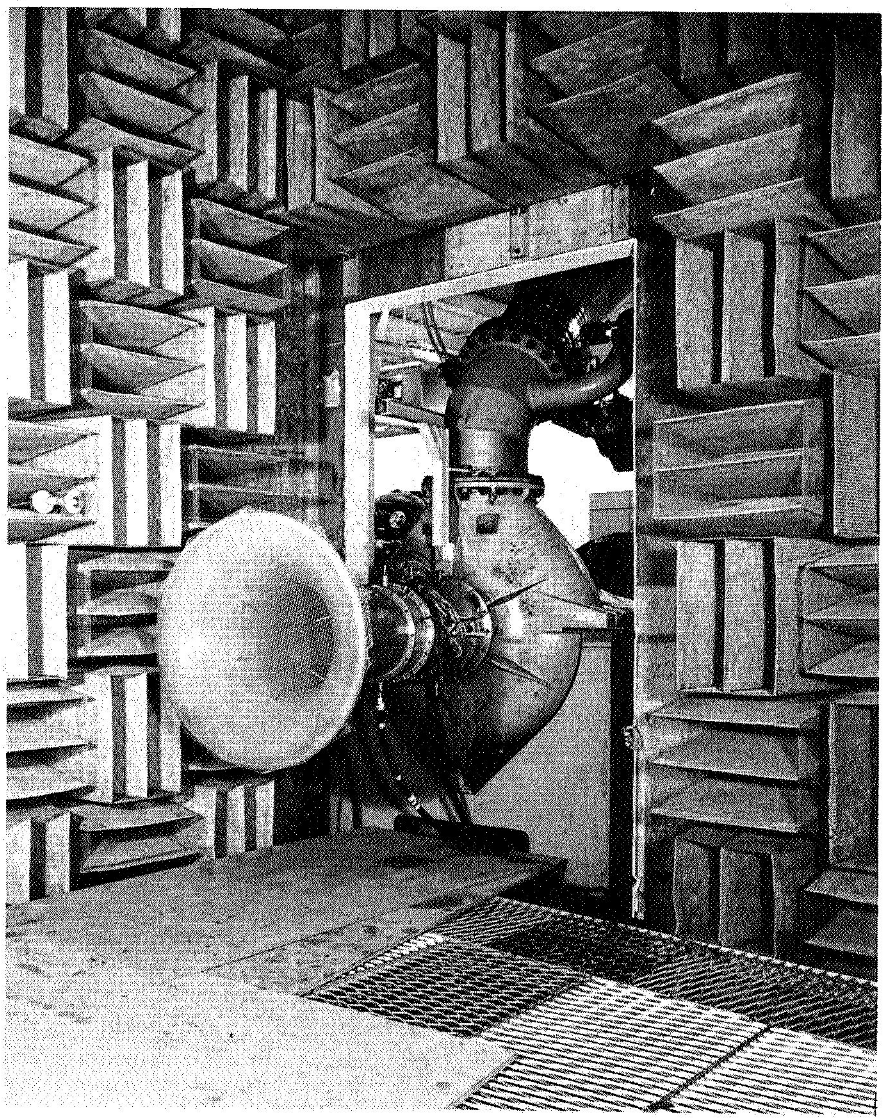


Figure 28.- Compressor noise studies.

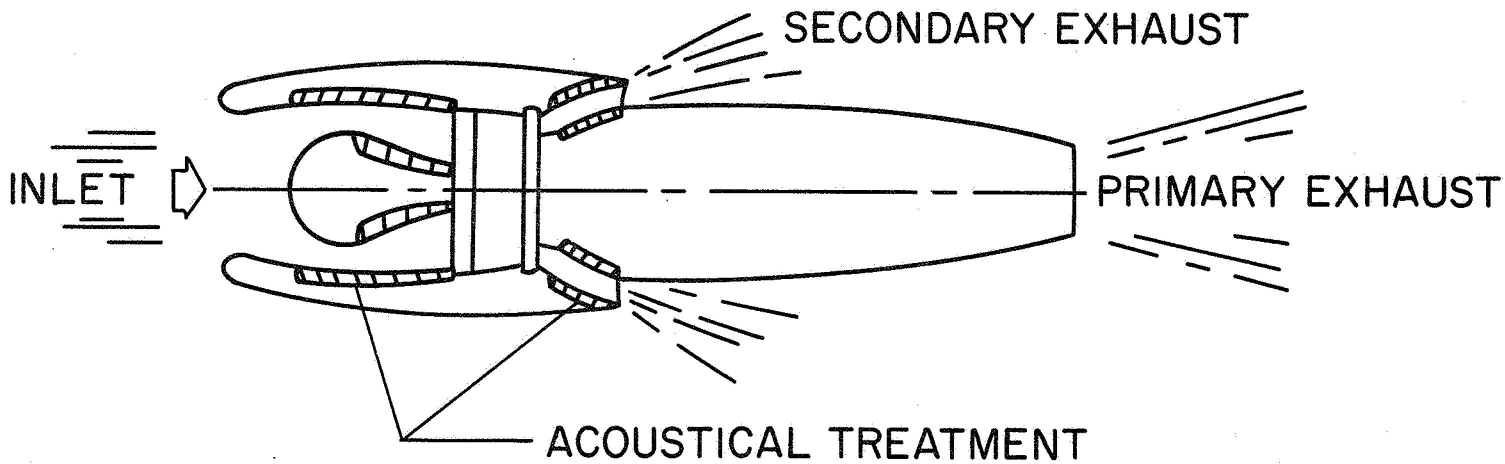


Figure 29.- Boeing and Douglas are developing nacelle treatments to reduce noise under NASA contract.

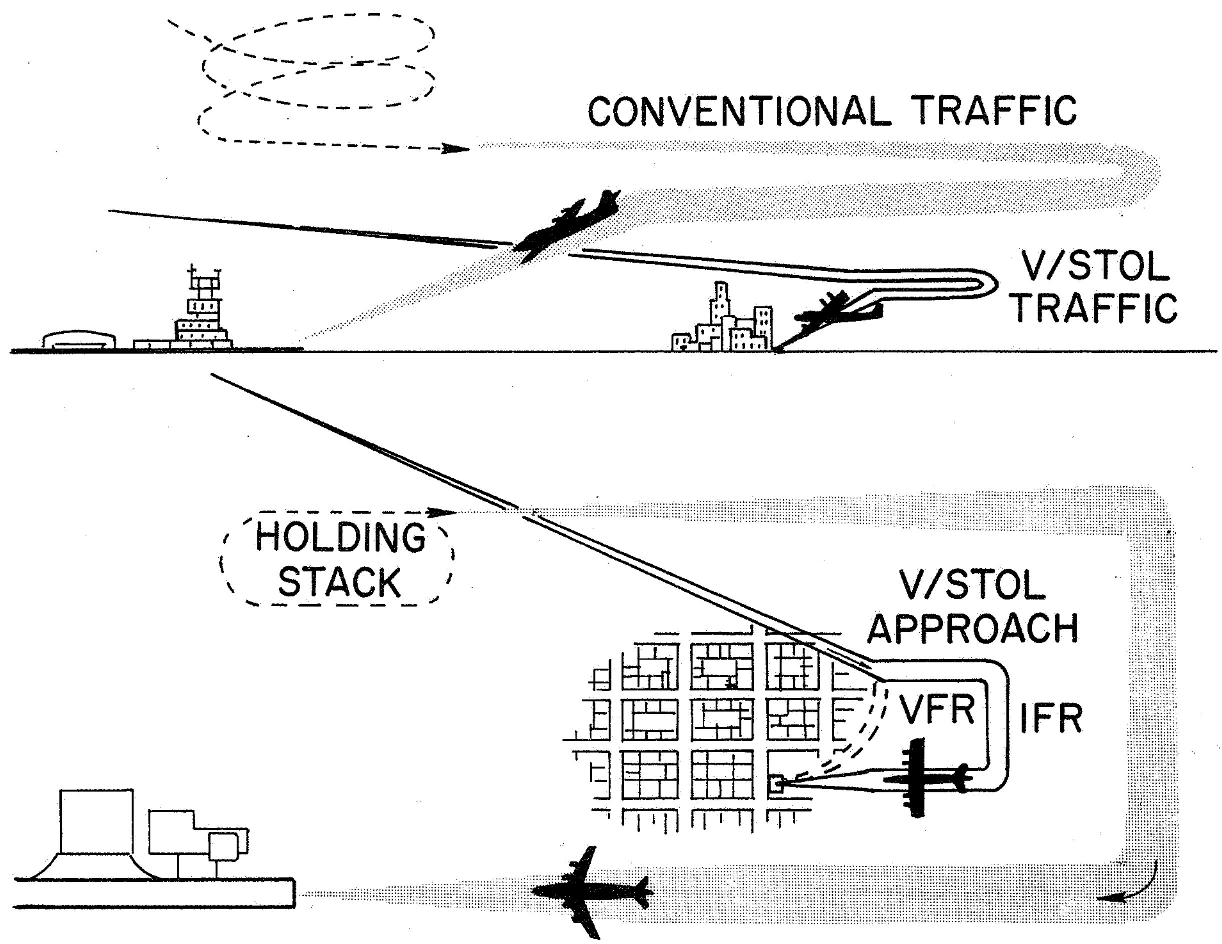


Figure 30.- To minimize delays from traffic congestion V/STOL and STOL aircraft will probably have to operate under conventional traffic in the terminal area.

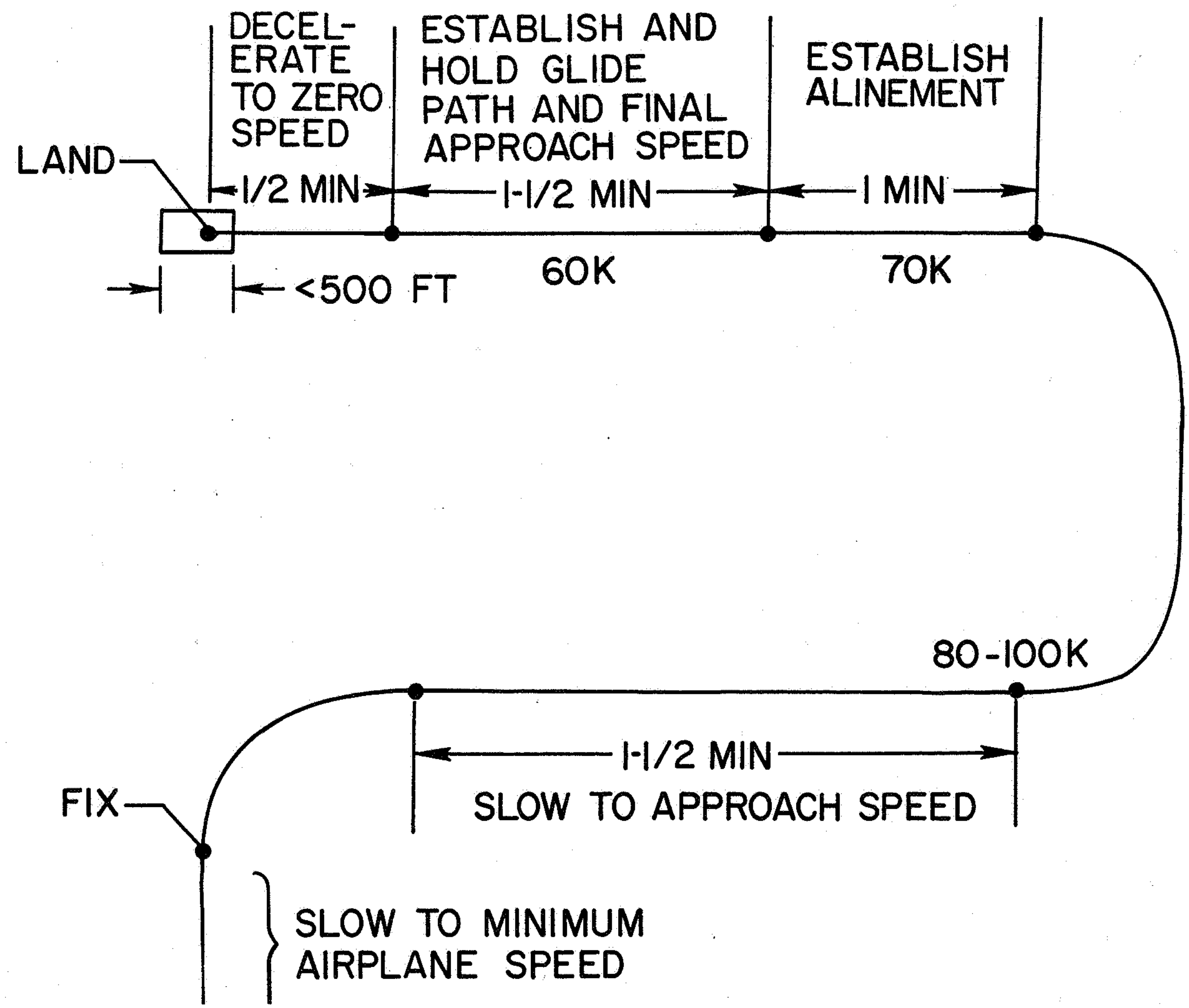


Figure 31.- With today's instrumentation all aircraft including V/STOL's must fly time-consuming approach patterns.

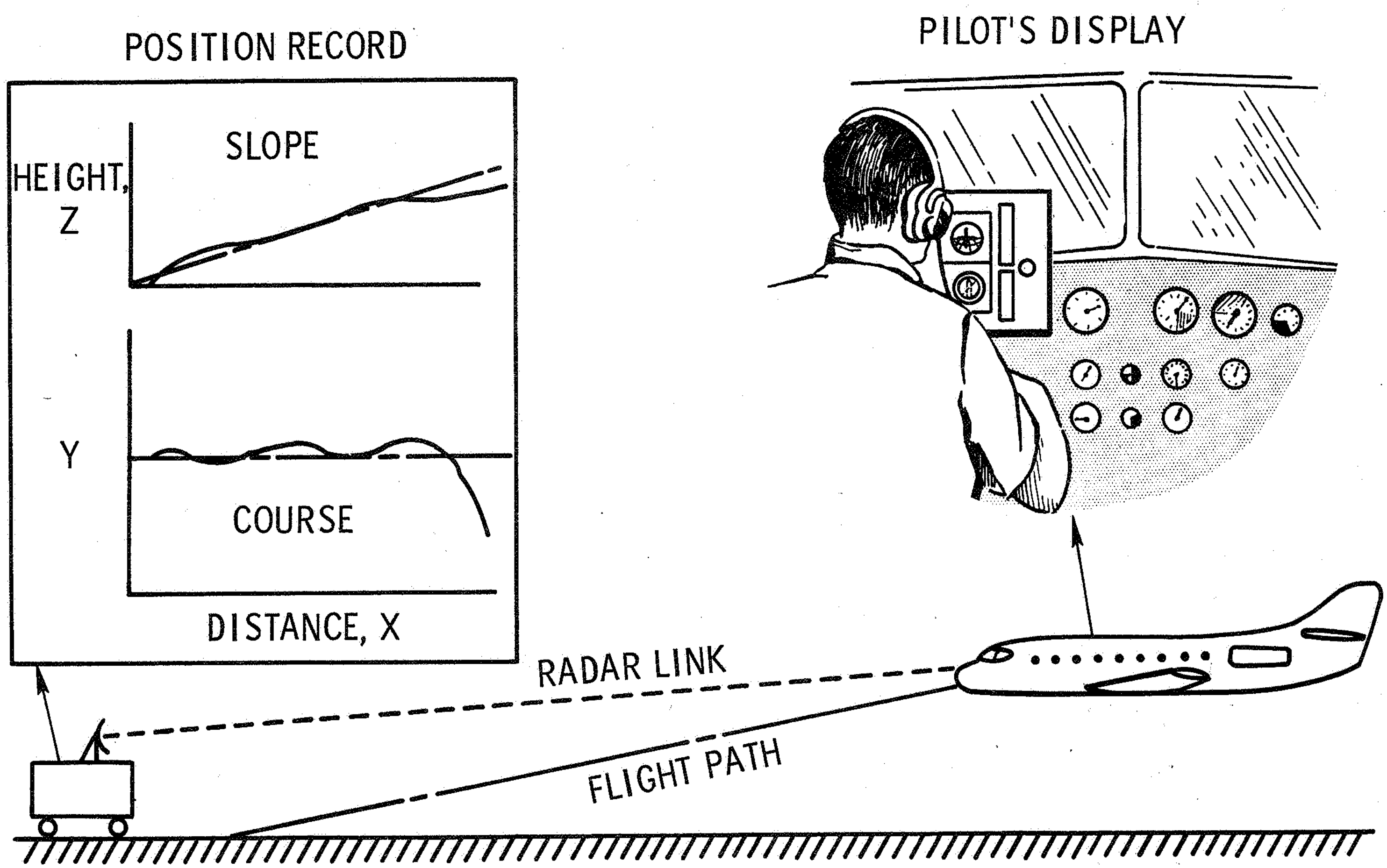


Figure 32.- NASA landing approach guidance research equipment.

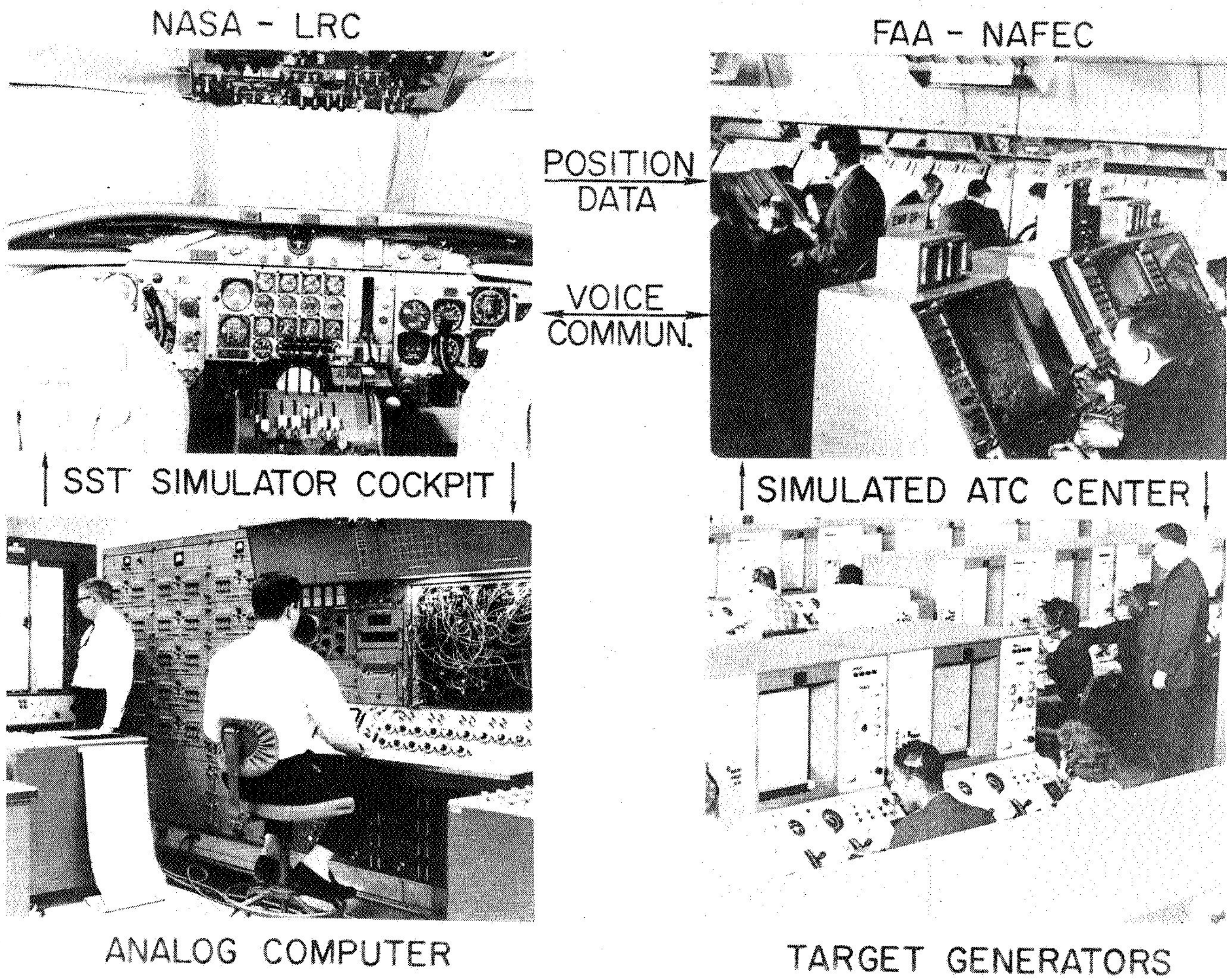


Figure 33.- SST-ATC simulation method.

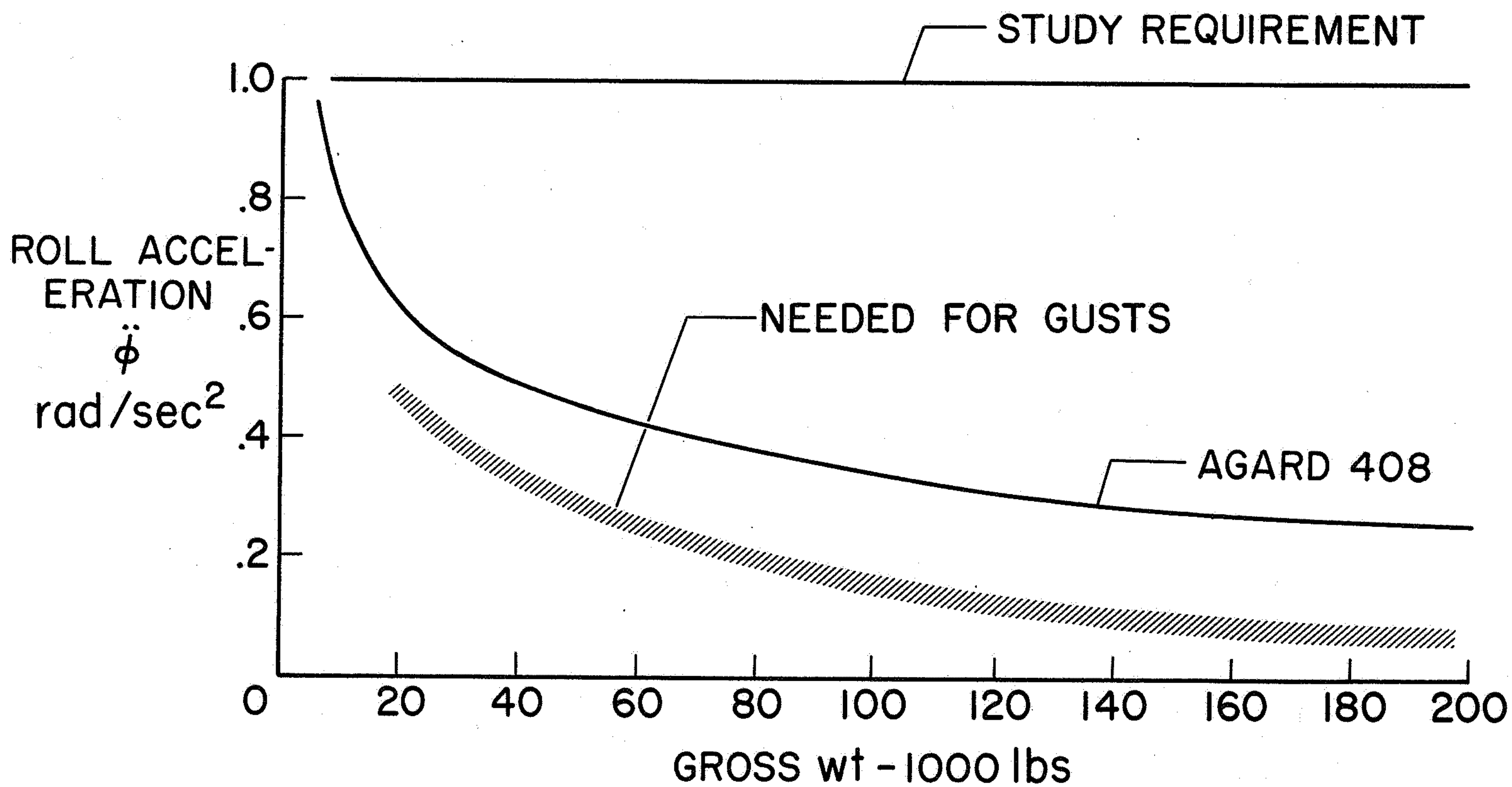


Figure 34.- The effect of aircraft size on control power requirements is still being studied.

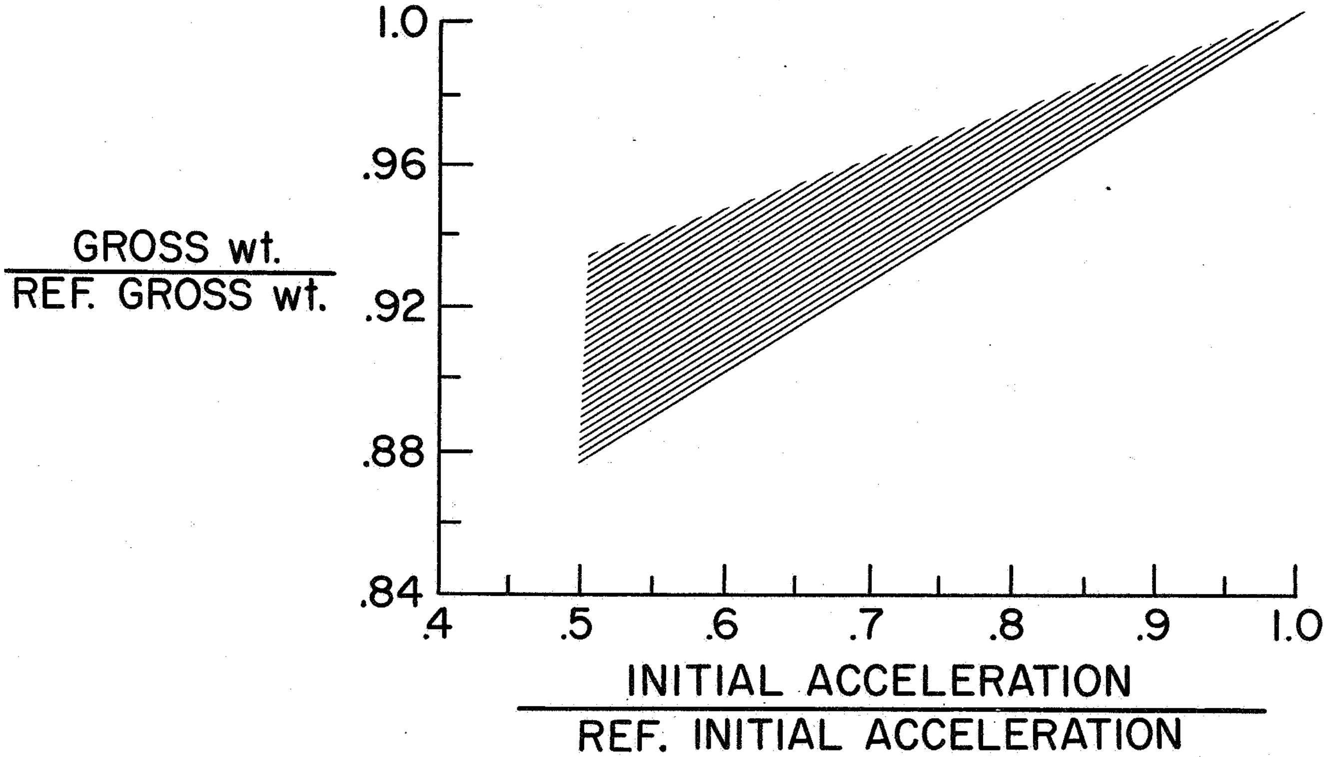


Figure 35.- Effect of control power requirement on gross weight.

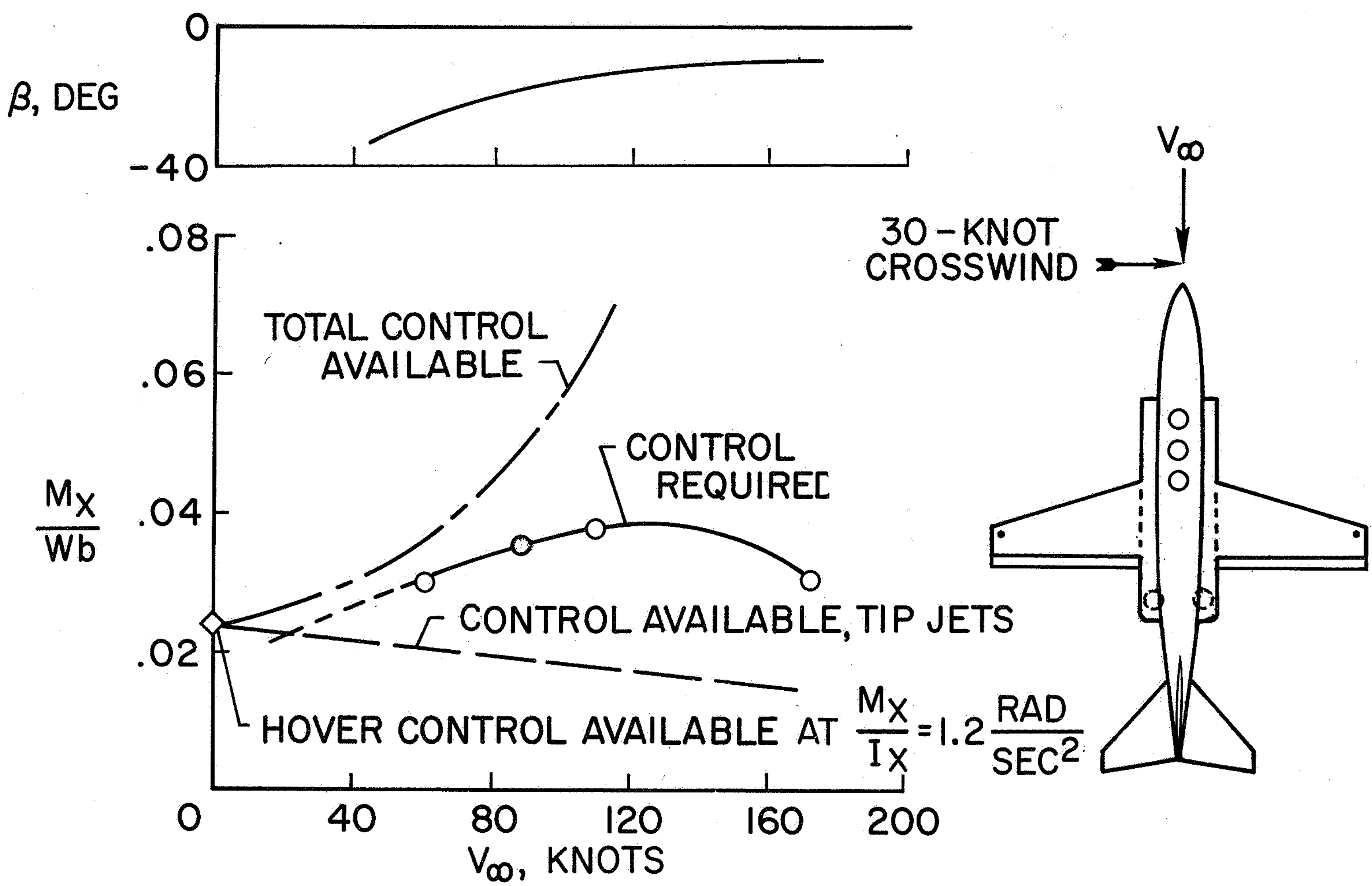


Figure 36.- Trim changes such as rolling moments that can be induced on fan and jet configurations should be minimized.

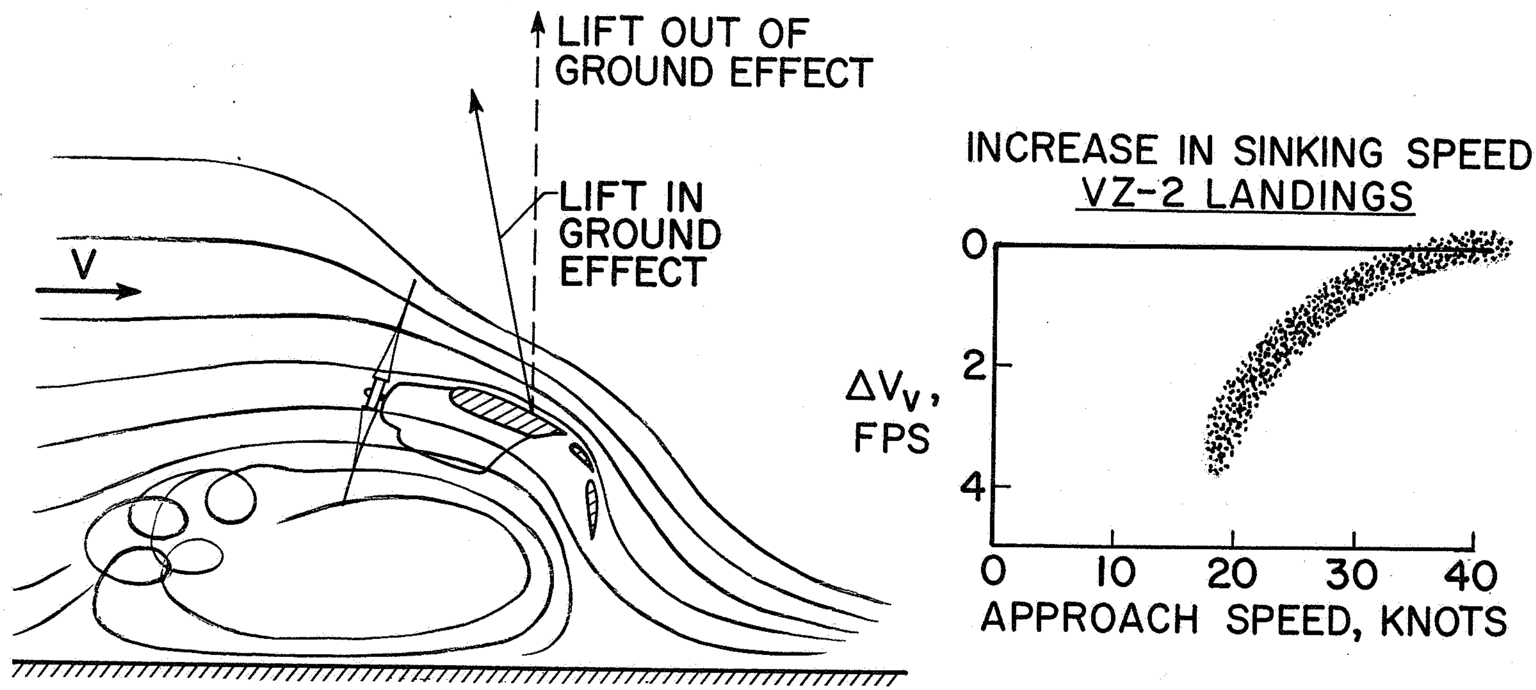


Figure 37.- Impingement of slipstreams on the ground create dust and debris problems as well as affecting performance.

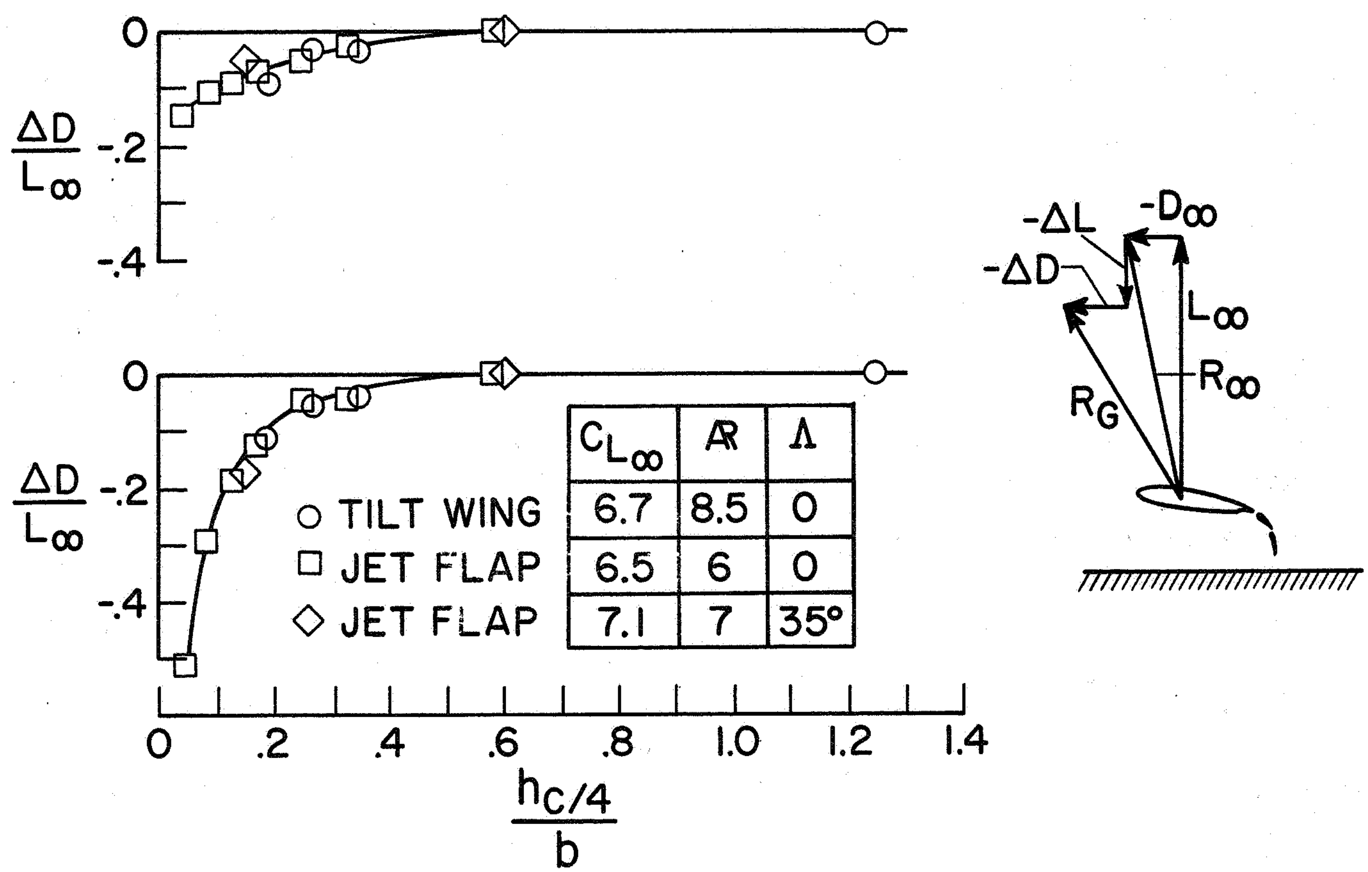


Figure 38.- Effect of ground proximity on aerodynamic forces.

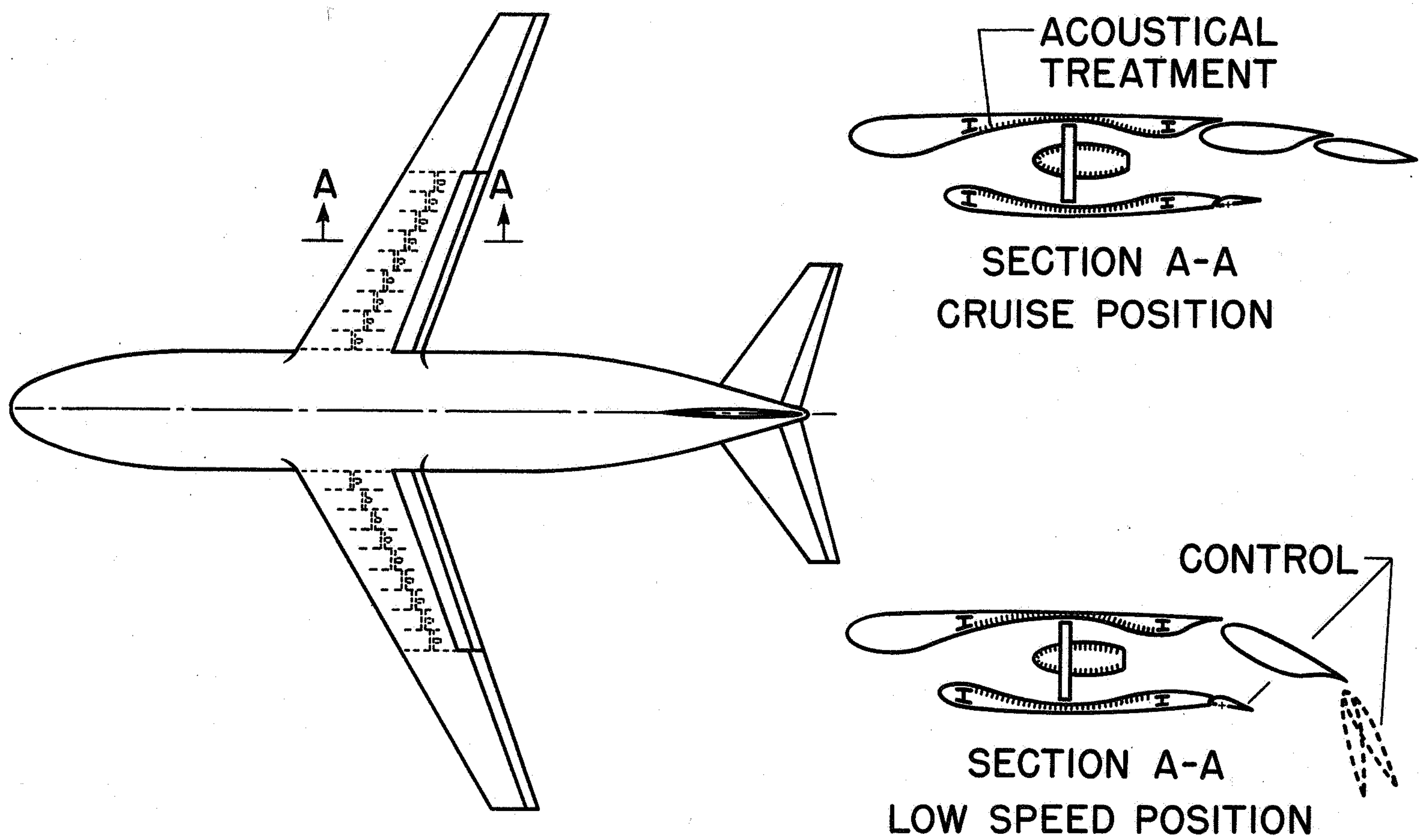


Figure 39.- Multiengine jet flap STOL air bus.

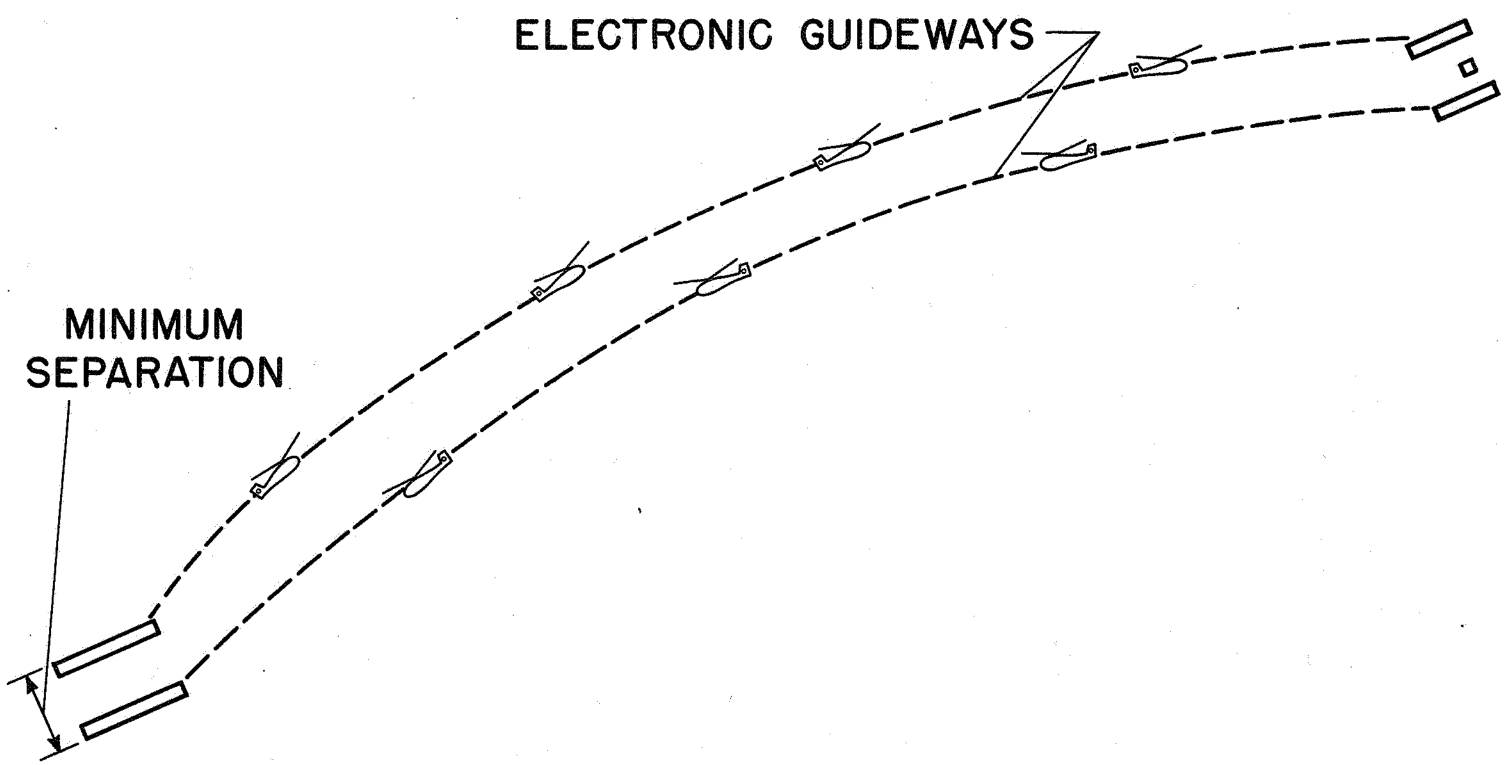


Figure 40.- V/STOL and electronic technology may provide inexpensive guideway for high-density traffic.

NASA-Langley, 1967